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AIRPORT SURFACE TRAFFIC CONTROL SYSTEM REQUIREMENTS ANALYSIS.(U)

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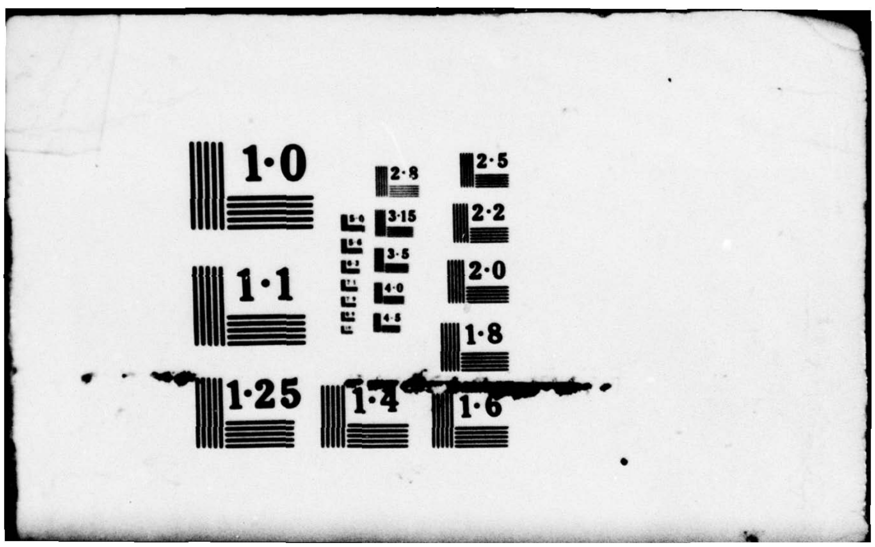
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16. Abstract

This report documents the results of an Airport Surface Traffic Control (ASTC) requirements analysis. Problems and potential payoffs are explored in the areas of capacity and delay, productivity, safety, and equipment limitations. Alternative approaches to solving ASTC problems are identified and their costs estimated. Benefits are estimated and ~~the~~ alternatives compared. Recommendations are made regarding future ASTC development programs and studies.

The potential for Ground Control saturation during bad cab visibility is shown to exist at Chicago O'Hare today, and at Los Angeles and Atlanta by the mid-1980's. The Tower Automated Ground Surveillance (TAGS) concept, using multiple ATCRBS interrogators to add target identity to the output of the ASDE-3 in a single hybrid display, is recommended for development and deployment at these three airports.

Analysis shows that increased traffic forecasts could require two ground controllers at ten airports by the late 1980's. A Standard Taxiway Routing system might eliminate the second ground controller at eight airports, with annual benefits of $500,000.

Analysis of accidents occurring on the surface of ATC-towered airports reveals that 87%
~~87 percent~~ % of accident costs and 76% ~~percent~~ of fatalities occurred at the top 25 air carrier airports. A study is recommended to identify the causes and hypothesize solutions to this category of accidents. Another potential safety problem is lack of positive runway clearance assurance at airports which operate during bad cab visibility but do not qualify for an ASDE-3. A study is recommended to establish a cost constraint and technical feasibility of low-cost solutions.

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PREFACE

An analysis of the current and planned Airport Surface Traffic Control (ASTC) System was performed in accordance with the system requirements process described in FAA Order 1810.1 for the purpose of defining and validating potential future requirements.

The study was sponsored by The Federal Aviation Administration, Office of Systems Engineering Management, to provide the basis for preparation of an Engineering and Development Program Plan for future development efforts.

Previous studies sponsored by the ASTC program served as the primary source of analytical data.

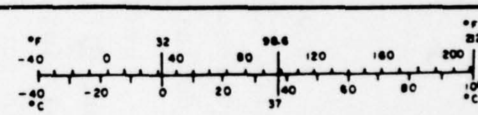
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

1. SYSTEM DESCRIPTION

The Airport Surface Traffic Control (ASTC) System controls the movement of traffic on to, through, and off of airport runways and taxiways. It encompasses people, procedures, and equipments.

Except at small airports, the aviation traffic on or in the vicinity of the airport is controlled by air traffic controllers in the tower cab. In general, two control positions are involved, ground control for taxiway movements and local control for runway management. Communication with the aircraft is by voice radio.

During good cab visibility conditions, visual surveillance usually provides the controllers with all the information they need to do their job and, in general, neither ground control nor local control will limit airport capacity. However, when the cab controllers are unable to see all or portions of the airport surface due to bad weather (fog, snow, etc.) most tower cabs must rely on pilot position reports issued via voice radio to obtain information on the location of traffic. This increases voice radio channel loading and controller workload, and reduces the accuracy of target location information. As a result, the capacity of both ground and local control is reduced and aircraft delays can build up.

In response to the problems associated with bad cab visibility conditions, ASDE-2, a ground surveillance radar which gives a plan view display of surface traffic, was developed and deployed in the early 1960's. There are currently twelve ASDE-2's in operation. Recently, due to the growth in air traffic and the installation of Category II Instrument Landing Systems (ILS), a need has arisen for additional ground surveillance radars. This need has prompted the development of ASDE-3, a new ground surveillance radar. The development of ASDE-3 is now in progress and, in accordance with approved establishment criteria, it will be deployed to approximately 30 airports over the next few years.

2. MISSION NEED

There are several areas in which ASTC system improvement could potentially be made. These areas are discussed separately as follows:

A. Bad Cab Visibility Problems at Busy ASDE-3 Equipped Airports

A high quality ground surveillance radar such as ASDE-3 will give the cab controllers all the target location information which they require for airport surface operations. Since a local controller manages a sequence of arrivals and departures, it is a simple matter for him to associate the necessary flight identity with each radar target by using a sequence of flight progress strips. Therefore, ASDE-3 will restore all the capacity which the local controller loses during bad cab visibility conditions. However, the taxiway traffic which the ground controller handles is not as well sequenced as that of local control but rather is spread out about the airport surface. Therefore, the ground controller continues to utilize pilot position reports to maintain knowledge of the identity of the radar targets. Because of this, and the added workload associated with these position reports, ASDE-3, while of some help to the ground controller, will not restore all the capacity which he loses during bad cab visibility conditions.

Due to the capacity limitations of ground control, even with an ASDE-3, the ground control function can currently become saturated during bad cab visibility conditions at Chicago's O'Hare Airport. In addition, based upon the latest FAA aviation traffic forecast, it is estimated that such saturation will occur at Atlanta Hartsfield and Los Angeles International airports by the mid 1980's. This saturation not only can cause delays, but places pressure on the ground controller to operate at or above his saturation capacity which can possibly impact on safety.

Currently at Chicago O'Hare, and by the time saturation occurs at the other two airports, the ground control function will be staffed by two ground controllers. As the pacing ground

controller reaches saturation, it would seem possible to add a third ground controller to ease the problem. However, this is not the case. At some airports today (e.g., Denver Stapleton) the addition of a second ground controller, even in good visibility conditions, can be a difficult procedure to work out due to the level of inter-controller coordination required in heavily congested taxiways and ramps. In bad cab visibility conditions with controllers relying on unidentified radar targets, this problem becomes even more severe. Such coordination limitations would only get worse if an attempt were made to add a third ground controller. Therefore, no simple procedural and staffing solution to the two ground controller saturation problem appears practical.

B. Bad Cab Visibility Problems at Non-ASDE-3 Equipped Airports

ASDE-3 is designed to provide all the location information required by cab controllers at a busy airport during bad visibility conditions. This objective imposes severe requirements on the radar system, with a resulting estimated cost of $870,000 (1978 dollars) for a production model. On a cost-benefit basis, these system costs limit the ASDE-3 deployment to about thirty airports.

Wherever ASDE-3 is installed, it will provide for safe and efficient movement of traffic during bad cab visibility conditions, except at the very busy airports (see 2.A) However, the deployment of Category II ILS Systems is wider than that of ASDE-3 so that some non-ASDE-3 equipped airports will be required to operate during bad cab visibility conditions. Since the deployment of Category II ILS is quite recent, a suitable data base does not exist from which to forecast future problems during these conditions. Nevertheless, the potential for serious problems exists. During a Category II approach, an approaching pilot cannot see if the runway is clear, and without an ASDE-3, neither can the cab controllers. A lost pilot or service vehicle operator occupying the active runway could result in a catastrophic accident.

C. Safety Improvements

Most accidents which occur on the airport surface are not directly related to surveillance limitations during bad cab visibility conditions. In the period from January 1964 to December 1976, 92 such accidents occurred at airports with FAA operated control towers. Of these accidents, 81 percent of all accident costs (27 million in 1978 dollars) and 3 of the 7 fatalities occurred at air carrier airports handling over 100,000 air carrier operations per year. This currently represents 25 airports, only 5 percent of all towered airports. Therefore, it appears that a significant potential safety improvement could be made at a relatively concentrated set of airports.

D. Productivity Improvements

At a few busy airports today, two ground controllers are required on a regular basis. By the late 1980's it is estimated that two ground controllers will be used regularly at about ten airports. Addition of a second ground controller often causes inter-controller coordination problems. If something could be done to eliminate the need for two ground controllers, these problems could be eliminated and productivity benefits (i.e., reduced staffing costs) could be realized.

3. BACKGROUND

In 1966, the FAA formally recognized the potential problems associated with airport surface operations through the issuance of an FAA System Requirement (FAAR 5355.1) to "Develop All-Weather Surface Guidance and Control Subsystems." In 1971, following a period of problem definition, a major new program was established to generate future ASTC system requirements and to develop systems and techniques required to meet the requirements. To guide the ASTC program, an Engineering and Development Program Plan (EDPP) was prepared. That plan described a program in which certain near term system improvements for implementation, including ASDE-3, would be developed while the requirements for additional advanced ASTC systems were studied. Advanced system studies were to include the brassboard testing of technologies which were applicable to

airport surface problems. In September 1973, an Acquisition Plan (AP) summarizing the program plan was prepared and submitted for review by the Transportation Systems Acquisition Review Council (TSARC). TSARC approval was obtained in October 1973 and the first phase of the ASTC program was initiated.

The ASTC program is now preparing to enter into an advanced system development phase. Entry into this phase will require an updated EDPP. This System Requirements Report is intended to support this document and to serve as a vehicle for agency approval.

4. OPTIONS AND ALTERNATIVES

The following system concepts are considered by this study as alternatives aimed at satisfying the mission needs.

A. Tower Automated Ground Surveillance (TAGS).

This is a system whereby target identity labels can be added to an ASDE-3 display. The system utilizes the ATCRBS beacon currently installed on aircraft for airborne application. In addition to adding the needed target identity, use of the ATCRBS beacon will enhance the overall system performance during precipitation and will permit the use of the beacon Ident feature in ground operations.

B. Automatic Intersection Control (AIC)

This is a computer based system which automatically resolves conflicts between aircraft at taxiway intersections. The system uses inductive loops buried in the taxiways to detect oncoming aircraft, and stop bars composed of a row of red in-pavement lights to signal the appropriate aircraft to stop.

C. Standard Taxiway Routing (STR)

This is a computer based system which automatically generates standardized taxiway routes for aircraft about to enter the taxiways. The routes would be transmitted to the aircraft via the planned Discrete Address Beacon System (DABS) data link. The same cockpit-pilot interface used to transmit flight plan information would be used by the standard taxiway routing equipment. The

system would generate the routes in terms of existing taxiway names and sign systems. Sets of maps giving all possible routes, versus all possible route determination parameters (e.g., runway configuration in use) would not be required in this system (as opposed to some standard taxiway routing concepts).

D. Automatic Ground Control System (AGCS)

This is a fully automatic ground control system. The system would be composed of an airport-wide deployment of inductive loops to detect aircraft entering or exiting any taxiway link, red stop bars at every taxiway intersection to permit conflict control, and green directional centerline guidance lights installed through each taxiway intersection to permit routing commands.

E. Positive Runway Clearance Assurance System

This is a low cost surveillance system aimed at providing general runway occupancy information to local control on runways with Category II landing minimums. System alternatives include a low resolution x-band ground surveillance radar (i.e., a low cost ASDE), and a fixed antenna pulse Doppler (x-band) radar pointed down the Category II runway. Two such systems are in operation in Europe.

F. Tower Automated Ground Surveillance (TAGS) System Enhancements

If TAGS is installed, the aircraft identity and location information which it provides in digital form can be used to implement automation features. Features include Conflict Alert, and Local Controller Runway Control Cues. If DABS data link is interfaced with TAGS, features can be extended to provide automatic conflict control or the full automation of ground and/or local control functions.

5. ANALYSIS

The analysis treats each of the problem areas individually as follows:

A. Bad Cab Visibility Problems at Busy ASDE-3 Equipped Airports

Ground Control service time per aircraft increases substantially during bad cab visibility conditions reducing the operations rates at which the ground controller will saturate. By the mid 1980's such saturation is expected to occur at Chicago O'Hare, Atlanta Hartsfield and Los Angeles International Airports. If no system improvements are forthcoming, capacity limitations associated with this saturation are estimated to result in average annual delay costs of $1.8 million (1978 dollars) per airport by the late 1980's.

The candidates for increasing the ground controller's capacity are Tower Automated Ground Surveillance, TAGS, (by reducing the need for pilot position reports), Automatic Intersection Control (by reducing the need for intersection conflict resolution), Standard Taxiway Routing (by reducing the need for initial routing) and Automatic Ground Control Equipment (by automating ground control functions). The workload at several airports was analyzed and the potential improvement associated with each alternative was estimated. The results indicate that only TAGS and possibly the Automatic Ground Control System will provide adequate capacity improvement. Automatic Intersection Control and Standard Taxiway Routing taken together do not provide for adequate ground control capacity. Furthermore, comparison of TAGS and the Automatic Ground Control System costs indicates that TAGS is by far the cheaper of these two alternatives. Therefore, TAGS was selected for additional study.

A formal present-value cost/benefit analysis was performed comparing a TAGS development program with the alternative of doing nothing. Results indicate that a TAGS development program would indeed be cost beneficial and that the results are quite insensitive to parameter variations such as cost overruns and schedule slips. The proposed program costs are estimated at $8.7 million (1978 dollars) for development and $5.8 million (1978 dollars) for

deployment of three systems. With these costs the program would realize a benefit/cost ratio of 2.6 and a net present value (base year 1976) of $18.6 million (1978 dollars).

B. Bad Cab Visibility Problems at Non-ASDE-3 Equipped Airports

At non-ASDE-3 equipped airports which operate a Category II ILS system, no positive runway clearance assurance may be provided to the pilot of an approaching (or departing) aircraft. The least expensive system now in operation which could provide such assurance is a low cost ASDE at $150,000 (1978 dollars). With an estimated cost of $550,000 (1978 dollars) for upgrading a Category I ILS facility to a Category II ILS facility, addition of a low cost ASDE would add about 25 percent to the system upgrading costs. These added costs might not grossly affect the net benefits associated with a Category II ILS system. The potential seriousness of an accident which could result from the lack of such positive runway clearance assurance points up the need for a study of Category II ILS benefits sensitivity to increased system cost, and the generation of a rational cost constraint for a system to provide such assurance.

C. Safety Improvements

The majority of the nonsurveillance related accident costs occur at the top 25 air carrier airports. If some improvement could be found which would prevent these accidents, and it was deployed at the 25 top air carrier airports, the improvement could accrue a savings of $66,000 (1978 dollars) per year per airport in accident related costs. Amortizing improvement costs over 15 years at 10 percent and adding operating and maintenance costs at nine percent of the initial capital investments, these savings could pay for improvements requiring an initial capital investment of less than $304,000 (1978 dollars). To define such an improvement, estimate its cost, and estimate its actual potential safety benefit would require a detailed examination of each accident which occurred in the sample period. Such an analysis has not been conducted to date. However, the allowable initial capital investment costs points to the need for such an analysis.

One set of safety related improvements which is evident are TAGS enhancements. If TAGS enhancements could be developed which would have prevented the accidents which occurred at the three TAGS sites in the 13-year period analyzed, a savings of $93,000 (1978 dollars) per year per airport would have been realized. Amortizing enhancement costs over 15 years at 10 percent and adding annual operating and maintenance costs at nine percent of initial capital investment costs, these savings could pay for enhancements requiring an initial capital investment of less than $428,000 (1978 dollars). Therefore, the consideration of such enhancements should be included in any safety analysis performed.

D. Productivity Improvements

It is estimated that by the late 1980's approximately ten airports will require two ground controllers on a regular basis. Preliminary analysis results indicate that Standard Taxiway Routing equipment might prevent the need for adding the second ground controller at all but the two busiest airports, viz. Chicago O'Hare and Atlanta Hartsfield. At these two sites Standard Taxiway Routing, even with TAGS installed, will not permit operation with a single ground controller. At the eight candidate sites the installation of Standard Taxiway Routing equipment could accrue annual benefits (controller staffing reductions) of $63,000 (1978 dollars) per year per airport. Amortizing enhancements costs over 15 years at 10 percent and adding annual operating and maintenance costs at nine percent of initial capital investment costs, these savings could pay for a Standard Taxiway Routing system requiring an initial capital investment of less than $286,000 (1978 dollars).

6. RECOMMENDED COURSE OF ACTION

Based upon the ASTC requirements analysis results, the following recommendations are made.

A. TAGS Development and Implementation Program

As a solution to the bad cab visibility problem forecast for Chicago O'Hare, Atlanta Hartsfield and Los Angeles International airports, it is recommended that a TAGS system be developed and that systems be installed at these three sites. Of the system

alternatives which can potentially solve this problem, TAGS is the most cost-effective. Compared with a "do-nothing" alternative, TAGS is cost-beneficial. TAGS will not only reduce user delay costs, but will relieve the pressure which would otherwise be placed on controllers to operate at and beyond their saturated capacity. Thus, TAGS will help to prevent situations which could degrade system safety. In addition, TAGS will serve as a vehicle for future enhancements which might help to improve safety in all visibility conditions and which might be required to realize capacity gains forecast for Advanced Metering and Spacing and reduced separation standards. The recommended program should result in the operation of three TAGS systems by the mid-1980's. If possible, a system should be provided to Chicago O'Hare earlier since that airport has a current requirement for a TAGS system.

B. A Positive Runway Clearance Assurance System Study

Due to the serious nature of the type of accident which might occur during Category II operations without an ASDE-3, it is recommended that the feasibility of providing an alternative runway clearance assurance system be investigated. The study should review the costs and benefits associated with a Category II ILS installation. Based on the cost/benefit sensitivity to system costs, a rational cost constraint on a positive runway clearance assurance system would be generated. System functional requirements should be developed and the costs of existing systems which satisfy the requirements compared with the cost constraint. If none of the existing systems are found to be acceptable, the technical feasibility of developing a new system to meet the functional requirements and the cost constraint would be determined.

C. An ASTC Safety Improvement Study

Due to the relatively large number of nonsurveillance-related accidents concentrated in a relatively few airports (i.e. the top 25 air carrier airports), it is recommended that a detailed study be made of each such accident which occurred at those airports over the last 15 years. (Twenty four accidents occurred between January 1964 and December 1976.) This examination will

permit the assessment of whether or not an aid or aids could have potentially prevented some of the accidents. If such aids are identified, preliminary designs and cost estimates should be made and a formal cost/benefit analysis conducted. TAGS enhancements such as conflict alert should be considered in the study for potential deployment to the three TAGS sites.

D. Standard Taxiway Routing System Feasibility Study

Due to the potential productivity gains which a successful Standard Taxiway Routing system could accrue, it is recommended that a feasibility study for such a system be conducted. The study should include preliminary system design to judge as to operational practicality at designated airports, system cost estimation, and a formal cost/benefit analysis using updated benefits estimates.

7. GUIDELINES GOVERNING TAGS ACQUISITION

The TAGS system must be capable of adding target identity labels to an ASDE-3 plan-view display without impacting on target detection and without imposing added ground controller workload. The intent of the system is to eliminate the need for pilot position reports during bad cab visibility conditions, thus freeing the controller to handle added aircraft. Only if an operational evaluation of a TAGS development model indicates that these system objectives can be realized, should the deployment of TAGS production models take place.

8. REFERENCES

1. Engineering and Development Program Plan-Airport Surface Traffic Control, Federal Aviation Administration, FAA-ED-08-1, July 1972.

2. Airport Surface Traffic Control Systems Deployment Analysis, Federal Aviation Administration, FAA-RD-74-6, January 1974.

3. Airport Surface Traffic Control Concept Formulation Study, Federal Aviation Administration, FAA-RD-75-120,I-IV, July 1975.

4. Airport Surface Traffic Control-TAGS Planning Alternatives and Cost/Benefit Analysis, Federal Aviation Administration, FAA-RD-77-9, January 1977.

5. Tower Automated Ground Surveillance (TAGS) System Alternatives Study, MITRE METREK Technical Report, MTR-79W00017, January 1979.

1. INTRODUCTION

1.1 SYSTEM DEFINITION

The Airport Surface Traffic Control (ASTC) system is defined as the portion of the Air Traffic Control (ATC) system responsible for traffic on the airport runways and taxiways. The system currently consists of two control positions, Local Control and Ground Control, which are stationed in the tower cab using visual surveillance and voice radio. Local Control handles traffic on the runways and in the airspace in the immediate vicinity of the airport, while Ground Control handles traffic on the taxiways and, at some airports, issues advisories regarding aircraft movement on the ramps. The only major ASTC equipment now in operation is ASDE-2, a ground surveillance radar currently operated at 12 airports to assist the controllers during poor cab visibility conditions. A Plan Position Indicator (PPI) display for ASDE-2 is shown in Figure 1-1.

1.2 PROGRAM BACKGROUND

As with all aspects of the ATC system, the continual increase in air traffic is placing increased levels of demand on the ASTC system. In addition, the reduction in landing minimums through increased installation of Category II and IIIa Instrument Landing Systems (ILS) is increasing the amount of time during which cab controllers and pilots must operate under poor visibility conditions. In 1966, the potential problems associated with these conditions were formally recognized by the Federal Aviation Administration (FAA) through the issuance of an FAA System Requirement (FAAR #5355.1) to "Develop All-Weather Surface Guidance and Control Subsystems." In 1971, a major new program was established to generate future ASTC system requirements and to develop systems and techniques necessary to meet the requirements.

Preliminary requirements analysis conducted early in the ASTC program indicates a growing problem in the area of surveillance, i.e., the means by which each controller determines

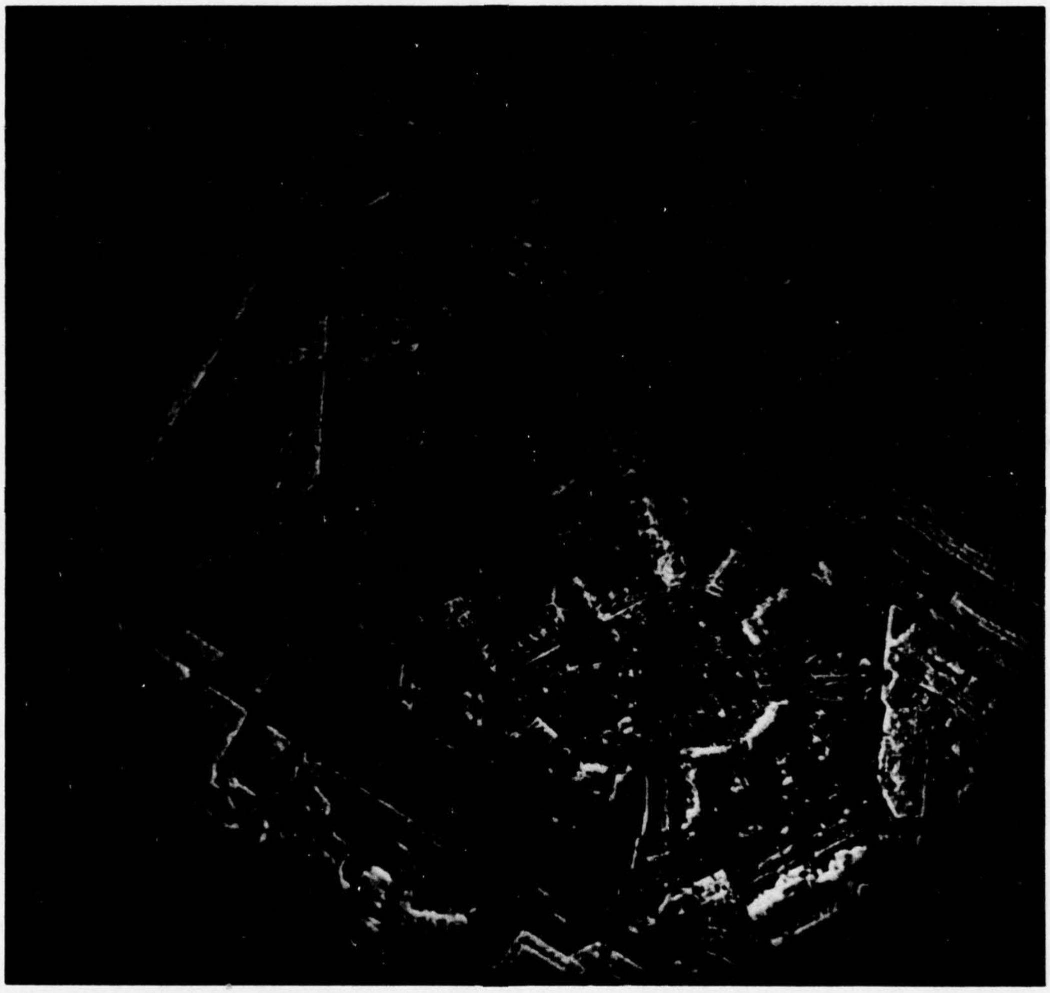


FIGURE 1-1. ASED-2 PPI AT NEW YORK JFK

airfraft location and identity. During bad cab visibility conditions at airports without ASDE-2, controllers are forced to rely solely on position reports from pilots over the voice radio. As a result, Local Control will add extra spacing between operations and Ground Control will, on occasion, find his voice radio channel becoming saturated. This adversely affects ASTC service. There are not enough ASDE-2's to go around and, even where installed, the ten-year-old radar suffers in performance during rainfall and has poor reliability. Furthermore, due to the lack of ARTS-type target identity labels, the ASDE-2 still requires Ground Control to ask for some pilot position reporting to help maintain target identity. At the very busy airports, even ASDE-2 appears inadequate.

In response to these problems, two new surveillance systems were conceived: ASDE-3, a new ground surveillance radar to replace ASDE-2 and provide for a wider deployment, and TAGS (Tower Automated Ground Surveillance), a system providing ARTS-type target identity labels for use at airports where ground surveillance radar alone is not adequate. In addition, a third system concept, Automatic Intersection Control (AIC), was defined as a means of improving ground controller productivity in all visibility conditions. The AIC system would automatically resolve conflicts at busy taxiway intersections through the use of buried inductive loops (for aircraft detection) and stop bars, in a fashion similar to city traffic lights.

Based upon these three system concepts, an Engineering and Development Program Plan (EDPP) was written (Reference 1.1) and a major System Acquisition Plan (dated September 1973) was prepared and submitted for review by the Transportation Systems Acquisition Review Council (TSARC). TSARC approval was forwarded on October 31 1973. The program plan is summarized in Figure 1-2. The key reports published to date under each task are also included in the figure.

As can be seen in the program task flow, the ASTC program has proceeded along three major directions, the development of near term products, the definition of advanced (beyond near term) system concepts, and the development of the technology required to implement the three most likely advanced system concepts.

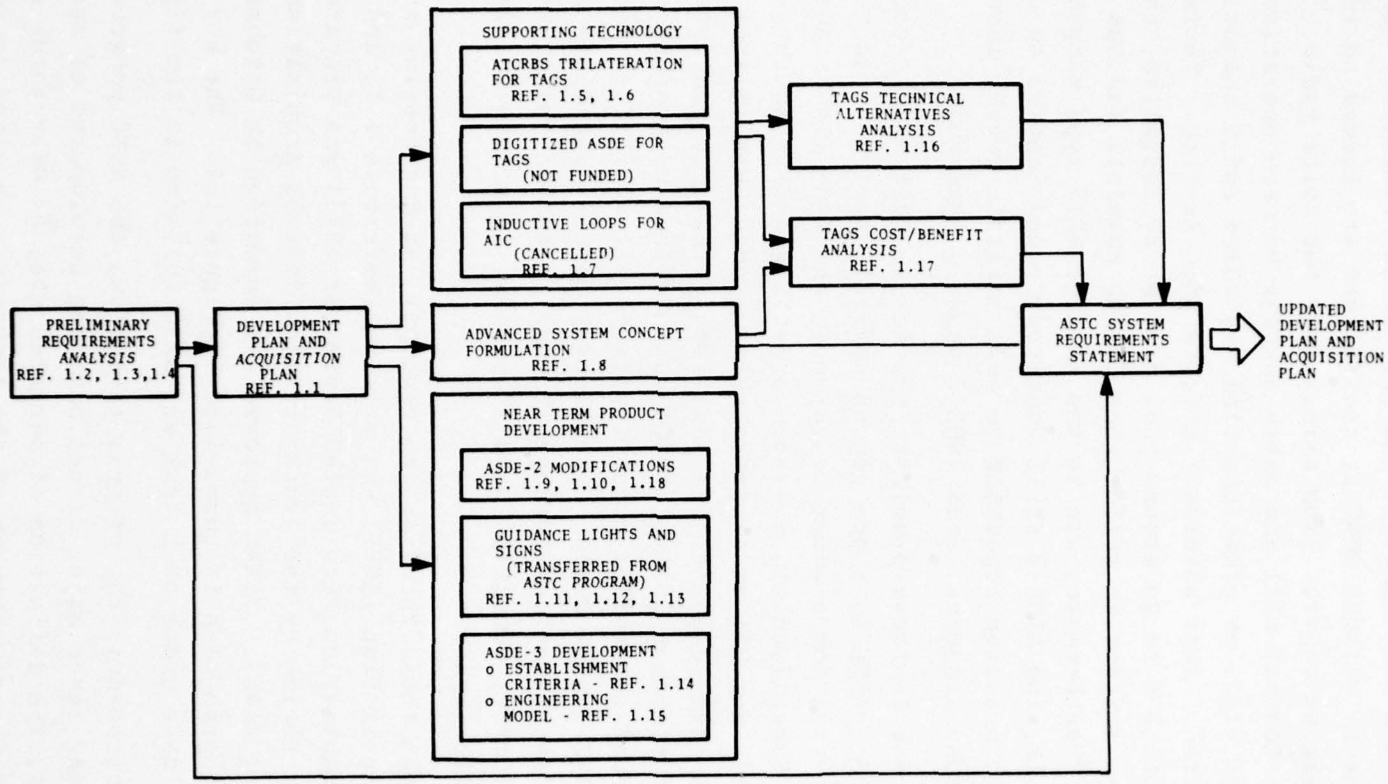


FIGURE 1-2. ASTC PROGRAM TASK FLOW CHART

Under near term activities, the ASDE-2 modifications have been completed. Requirements analysis of the visual aids has been conducted resulting in an engineering and development plan, with the responsibility for conducting the visual aids subprogram transferred out of the ASTC program. The establishment criteria for ASDE-3 has been prepared and approved by the FAA Administrator, and the development of the engineering model is in progress.

Of the supporting technology activities, only the ATCRBS trilateration effort has had continued funding. The digitized ASDE effort was never funded, and the AIC brassboard effort was initiated but cancelled prior to field installation and test. Both actions were due to restricted ASTC project funds with priority being placed on near term products and ATCRBS trilateration, the most promising technology area.

The third program area, Advanced System (TAGS) Concept Formulation, was funded and has been completed.

1.3 REQUIREMENTS STUDY OBJECTIVES

The ASTC program is now preparing to enter into an advanced system development phase. Entry into this phase will require an updated Engineering and Development Program Plan (EDPP). This system requirements report is intended to support the EDPP and to serve as a vehicle for agency approval. The report has been prepared in accordance with FAA Order 1810.1 "System Acquisition Management" and per that order the Executive Summary represents an ASTC System Requirements Statement (SRS).

As can be seen from Figure 1-2, a good deal of analysis has been conducted in support of this document. Following the Advanced System Concept Formulation Study, a TAGS Cost/Benefit Analysis was conducted. In addition, based upon the trilateration brassboard testing, a TAGS Technical Alternatives Analysis was conducted to determine the best means to implement the TAGS system. The approach taken in this study report is primarily to summarize and rely on this past work. However, some new analysis has been done and is noted in the relevant sections.

2. EVALUATION OF MISSION NEED

This section explores the problems associated with the ASTC system and estimates the potential payoff in correcting each problem. The problems are categorized into three broad areas and are treated separately. These problem areas are capacity limitations, reduced safety, and equipment limitations. Treated under capacity limitations is delay resulting from inadequate capacity, and productivity resulting from the need to add controllers to increase capacity and satisfy demand.

2.1 CAPACITY AND DELAY

2.1.1 Problem Definition

The flow of operations through the ASTC system is depicted in Figure 2-1. In general, arrivals enter through the terminal airspace under Approach Control and exit into the ramp area. Departures enter from the ramp area and exit into the terminal airspace under Departure Control. The airport capacity is determined by the pacing element in the flow of operations.

In examining the capacities of the Local and Approach/Departure Control elements, this study has relied on the latest capacity analyses of eight major airports provided in Reference 2.1. In these analyses an FAA airport capacity model is used which models the runways and their operating strategies (as exercised by Local Control). In addition, the ability of Approach Control to deliver arrivals, and of Departure Control to accept departures, is factored into the model. Ground Control capacity is not a part of the model. For Ground Control capacity estimates this study has relied upon the ASTC requirements analyses presented in References 1.3, 1.4 and 1.8 and summarized in Reference 2.2.

Figure 2-2 contains a comparison of capacity estimates of Ground Control with the "Airport Capacity" of the FAA model for the current system under VFR conditions at several airports. The

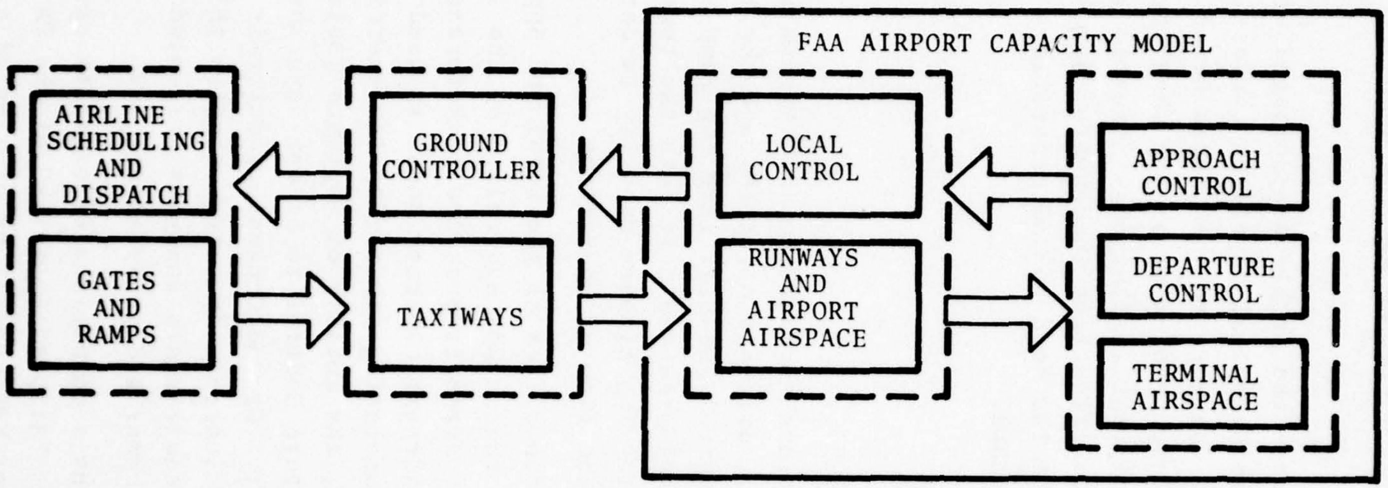


FIGURE 2-1. KEY ELEMENTS OF THE SYSTEM

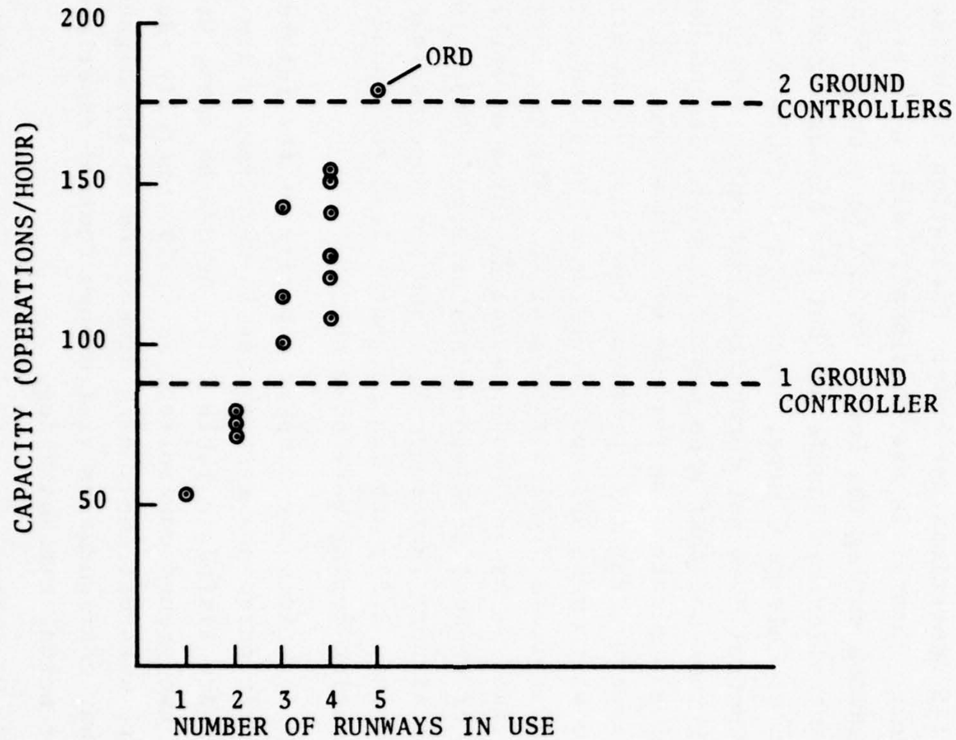


FIGURE 2-2. AIRPORT CAPACITY VS. GROUND CONTROL CAPACITY DURING VFR - CURRENT SYSTEM

limiting factor for Ground Control is controller workload as measured by voice radio channel occupancy time. Based upon voice channel tape recordings at nine different airports, it has been estimated that on the average, one ground controller will saturate at 88 operations per hour, and that two ground controllers will saturate at 175 operations per hour. Saturation is defined as having the voice channel in use continually with no break for at least five minutes during the hour. As can be seen in Figure 2-2, one ground controller can handle all but the highest capacity configuration at Chicago O'Hare. From this it could be concluded that Ground Control does not currently limit operations in good visibility conditions but that when demand is high, Ground Control at Chicago might experience some periods of saturation. This is true in general; however, capacity problems can exist if an airport is configured so as to make an equal division of workload between the two ground controllers difficult to achieve. The two controller capacity estimate is based upon an equal division of workload. This problem of unequal workload exists at Denver Stapleton International Airport (Reference 2.2) and Los Angeles International Airport (Reference 2.3), and can currently lead to ground controller saturation during very busy periods.

Figure 2-3 depicts the airport capacity of the future when all of the anticipated new systems now in development are installed. These systems are listed in Table 2-1. As can be seen, Ground Control with two ground controllers is still generally adequate. Only at O'Hare with extremely high demand and in the highest capacity runway configuration will Ground Control experience saturation under normal circumstances.

While Ground Control is not generally a pacing element in good visibility conditions, Local Control may be. In the FAA capacity model which generated the airport capacity estimates, it was assumed that Local Control could perfectly exercise the runway separation rules (e.g., if an arrival would exit the active runway before the next arrival crossed the threshold, it was assumed that the controller would anticipate this and clear the next arrival to

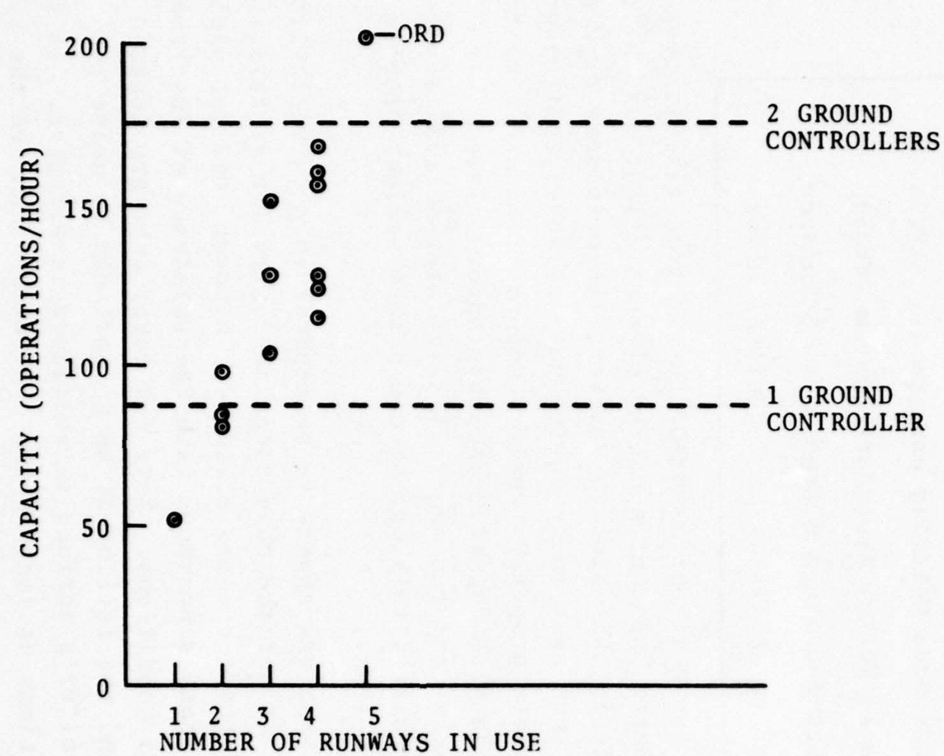


FIGURE 2-3. AIRPORT CAPACITY VS. GROUND CONTROL CAPACITY DURING VFR WITH GROUP 4 IMPROVEMENTS (EXCEPT ASTC IMPROVEMENTS)

TABLE 2-1. NEW ATC SYSTEMS ASSUMED TO GENERATE FUTURE AIRPORT CAPACITY

NEW ATC SYSTEMS (GROUP 4 - REFERENCE 2.3)
• Discrete Address Beacon System (DABS)
• Advanced Metering and Spacing (AM&S)
• Wake Vortex Avoidance System (WVAS)
• Reduced minimum Separation Standards
– to as little as 2 nautical miles

land). In this sense it was assumed that in good visibility conditions Local Control was not a pacing element. That assumption will also be made in this study. However, there is some evidence (Reference 1.8) that even today during busy periods, controllers can fail to estimate properly runway occupancy time and time-to-threshold and thus miss departure release opportunities. If metering and spacing and two nautical mile inter-arrival separations become a reality, this may become a more serious problem requiring further study.

While ASTC problems appear to be minimal in good visibility conditions, this is not the case when cab controller visibility of the airport surface becomes affected. However, bad cab visibility is by no means synonymous with the existence of Instrument Flight Rule (IFR) conditions. Very few tower cabs are located above 200 feet and the ceiling at an airport can be quite low before the controller's surface surveillance is affected. In fact, during IFR conditions as long as the controllers can see the airport surface, the operation can become simpler due to the reduced capacity of the terminal airspace. This is evident in Figure 2-4 which depicts the future airport capacity under IFR conditions but with good cab visibility. Under such IFR conditions, Ground Control is adequate everywhere including Chicago O'Hare, since O'Hare is unable to operate its high volume configuration in IFR conditions.

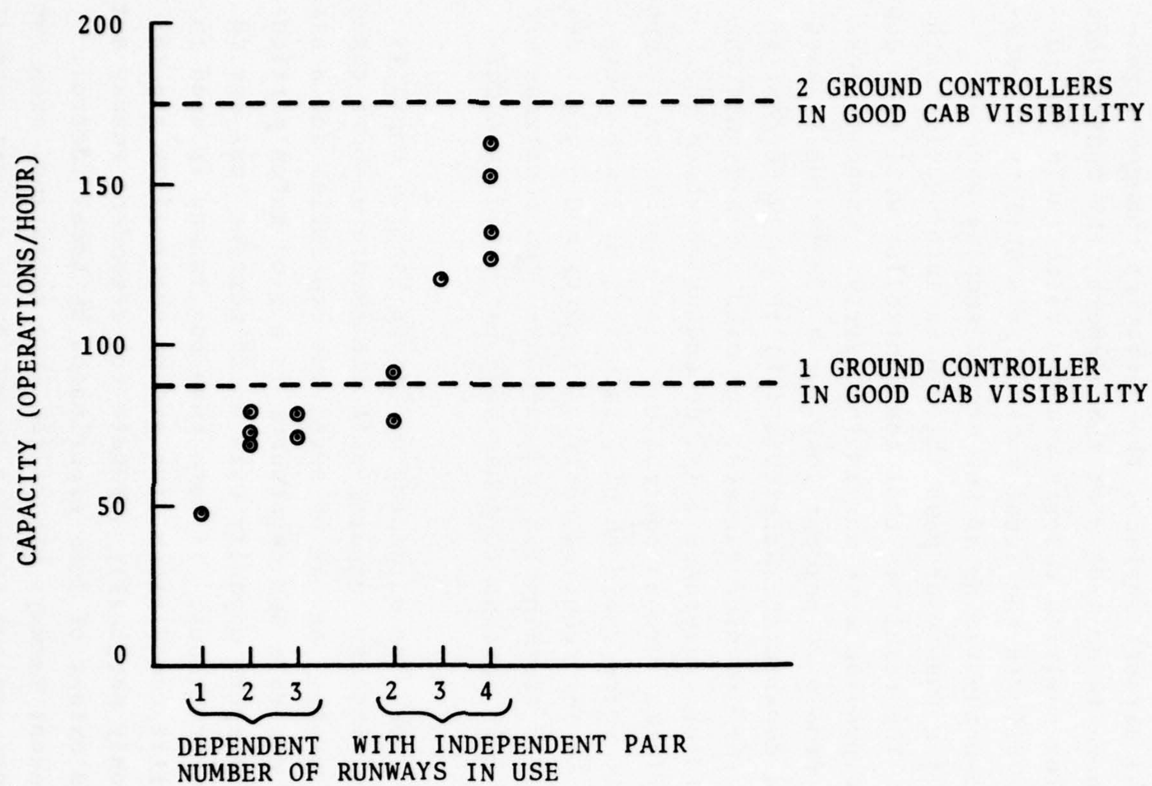


FIGURE 2-4. AIRPORT CAPACITY VS. GROUND CONTROL CAPACITY DURING IFR WITH GROUP 4 IMPROVEMENTS (EXCEPT ASTC IMPROVEMENTS)

When visibility conditions are such that the cab controllers lose sight of the airport surface, the operation changes significantly. If there is no ASDE-2 at the airport, the controllers must rely on pilot position reports via the voice radio for surveillance. This affects the local controller's ability to estimate and establish the timing of key events such as when an arrival will exit a runway or pass through an intersection with another runway. The result is that the controller will slow down the operation to provide more margin for safety. Capacity loss estimates range from a 20 percent loss for a single runway used for arrivals and departures (Reference 1.8) to an 11 percent to 22 percent loss for crossing runways, one used for arrivals the other for departures (Reference 2.1), depending on where the crossing takes place. Ground controllers also experience a capacity loss as their voice radio channel saturates at lower operations rates due to the required position reports and a great deal of inter-controller coordination required when two positions are staffed. Up to a 60 percent loss has been estimated (see Reference 2.2).

Figure 2-5 shows the estimates of Ground Control capacity during bad cab visibility compared with the future airport capacity during IFR conditions. As can be seen, one controller and a single runway used for arrivals and departures is a good match particularly since the airport capacity will be 20 percent less due to Local Control restrictions. If more than one runway is used in these low visibility conditions, two ground controllers are required and are only marginally adequate for dependent runway sets depending on the extent of loss experienced by Local Control. Once two independent runways are called into operation, even two ground controllers are not adequate to match the airport capacity, even with limitations due to Local Control. If demand warrants two independent IFR runways (e.g., with a Category II ILS) operating under bad cab visibility conditions (low IFR), two controllers are insufficient.

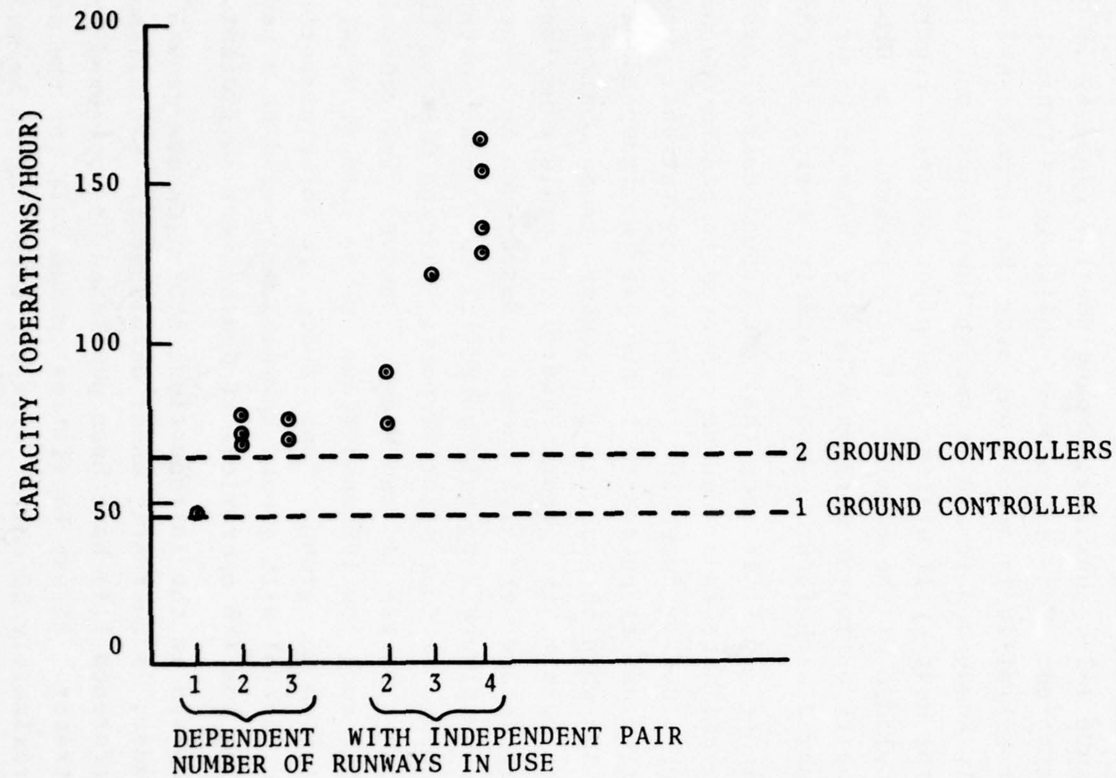


FIGURE 2-5. AIRPORT CAPACITY WITH GROUP 4 IMPROVEMENTS (EXCEPT ASTC IMPROVEMENTS) IN IFR VS. GROUND CONTROL CAPACITY DURING BAD CAB VISIBILITY WITHOUT AN ASDE

The addition of the ground surveillance radar to an airport restores virtually all capacity lost by Local Control. All timing information normally acquired visually is presented by the radar PPI (see Figure 1-1). However, Ground Control capacity is only partially restored. This is because, unlike Local Control, the Ground Control traffic is spread out over the airport surface and is not nicely sequenced to aid in target identification. The ground control must still utilize some pilot position reports to maintain knowledge of the identity of each target. The Ground Control Capacity estimates with an ASDE are shown in Figure 2-6 and are compared with future airport capacity during IFR conditions.

From Figure 2-6 it is seen that two ground controllers with a ground surveillance radar can be expected to handle adequately operations provided by dependent runway configurations. However, if an airport finds it necessary to operate two independent runways in low IFR when the cab, in particular Ground Control, cannot see taxiing aircraft, the ground controllers could experience saturation if demand were high enough. Based upon Reference 1.17, and as shown in Figure 2-6, this potential for Ground Control saturation occurs at four major airports, Chicago O'Hare, Los Angeles, Atlanta Hartsfield and Miami. However, Reference 1.17 indicates that such low IFR conditions are so rare at Miami as to eliminate it from the group. Thus, there are three airports for which Ground Control with ground surveillance could be a pacing element during low IFR operations if demand were sufficient.

As discussed in the Introduction, ASDE-3, a new ground surveillance radar, is currently under development. Establishment criteria (Reference 1.4) have been published and approved by the FAA Administrator. Airway Facilities' plans call for the deployment of approximately 30 units, with the first buy to be made from FY 80 funds. Therefore, this study will assume that where required a ground surveillance radar will be installed. With this assumption, the ASTC capacity and delay related problems may be summarized as follows:

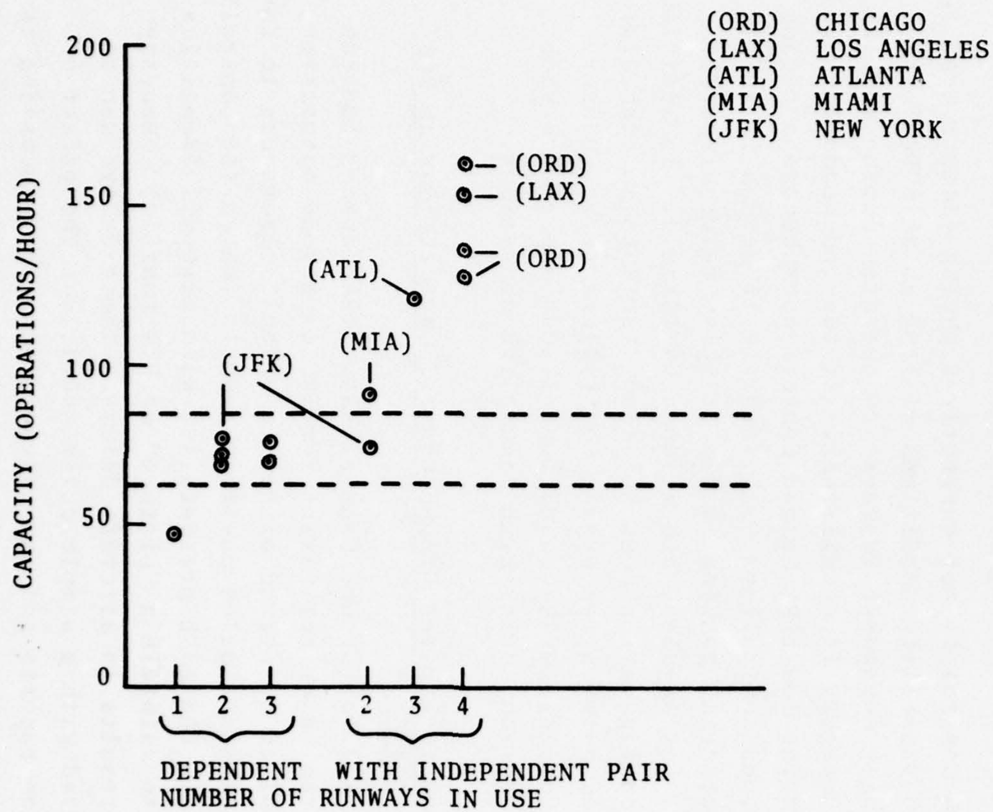


FIGURE 2-6. AIRPORT CAPACITY WITH GROUP 4 IMPROVEMENTS (EXCEPT ASTC IMPROVEMENTS) IN IFR VS. GROUND CONTROL CAPACITY DURING BAD CAB VISIBILITY WITH AN ASDE

1. Local Control is not currently a pacing element even in low IFR-bad cab visibility conditions as long as ASDE-3 is available should demand warrant it. It is further assumed in this study that Local Control will be able to handle future operations with increased arrival rates with existing equipment. This is an area which may warrant further consideration.

2. Ground Control is not currently a pacing element even in low IFR-bad cab visibility conditions as long as an ASDE-3 is available and only dependent runways are operated during low IFR (e.g., during Category II conditions). If two independent runways are operated during low IFR, Ground Control does become a pacing element and ground controllers will saturate if demand is sufficient. This potential problem exists at three major airports: Chicago O'Hare, Los Angeles, and Atlanta Hartsfield. In addition, if an airport configuration does not lend itself to an even division of workload between two ground controllers (e.g., Denver Stapleton and Los Angeles), Ground Control can experience some periods of saturation during high volume VFR operations.

2.1.2 Delay Due to Limited Ground Control Capacity During Bad Cab Visibility

The potential for Ground Control saturation during bad cab visibility is the major motivation for TAGS. Beyond saturation, a ground controller is forced either to withold clearances to taxi or reduce requests for pilot position reports (which the controller uses to correlate the ASDE presentation with aircraft identification in order to maintain a "picture" of his traffic). Denying taxi requests results in aircraft delays. These delays can be readily estimated with a simple delay model, but the effect of reduced position reports and saturated information processing is more difficult to measure. During such busy periods, the ground traffic can become congested and quite mixed up (arrivals with departures, etc.) Even when targets would normally be recognizable their identity can become confused. Position reports are useful to help draw the controller's attention to an aircraft at a critical location, as well as to provide identity and an open

communication link just when he needs it. Cutting back on such reports can increase the possibility of lost targets, missed critical events, and mistaken identities. The impact of saturation, therefore, has the dual role of causing delays and possibly impacting on safety.

A TAGS cost/benefits study is presented in Reference 1.17. Although the dual role of controller saturation is discussed, only the delays, computed via a simple delay model, are considered quantitatively. The delay costs represent a combination of actual delay costs and the pressure brought to bear on the controller to operate at and beyond his saturated capacity. This approach will also be taken here, and the results from Reference 1.17 utilized.

Reference 1.17 was completed in March 1976 using 1975 terminal area forecast data. Based upon this data, four, not three, airports were identified as potential TAGS sites, sites which would otherwise exhibit ground controller saturation. These sites included the three discussed in Section 2.1.1 but also included New York--JFK. However, a demand at JFK which would saturate Ground control would also saturate the airport capacity as presented in Reference 2.1, even with all planned improvements (see Figure 2-6). In the face of this apparent inconsistency, the latest Terminal Area Forecast (Reference 2.4) data was compared with the data used in the TAGS cost/benefit study for the four airports. The comparison is shown in Figure 2-7.

From Figure 2-7 it can be seen that New York JFK is now forecasted to exhibit a reduction in demand. This is due to an increase in the use of wide body jets and the growth of a fourth New York airport (in addition to JFK, Newark and La Guardia); namely, Stewart Airport in Newburgh, New York. Therefore, JFK is not expected to saturate either the airport capacity or Ground Control capacity and will not be a candidate for TAGS. The latest forecasts for the other three airports are quite close to those used in the 1975 cost/benefit study. Figure 2-7 also indicates the dates at which the 1975 study estimated Ground Control saturation would occur on a regular basis during bad cab visibility. The new forecast is not likely to alter these dates.

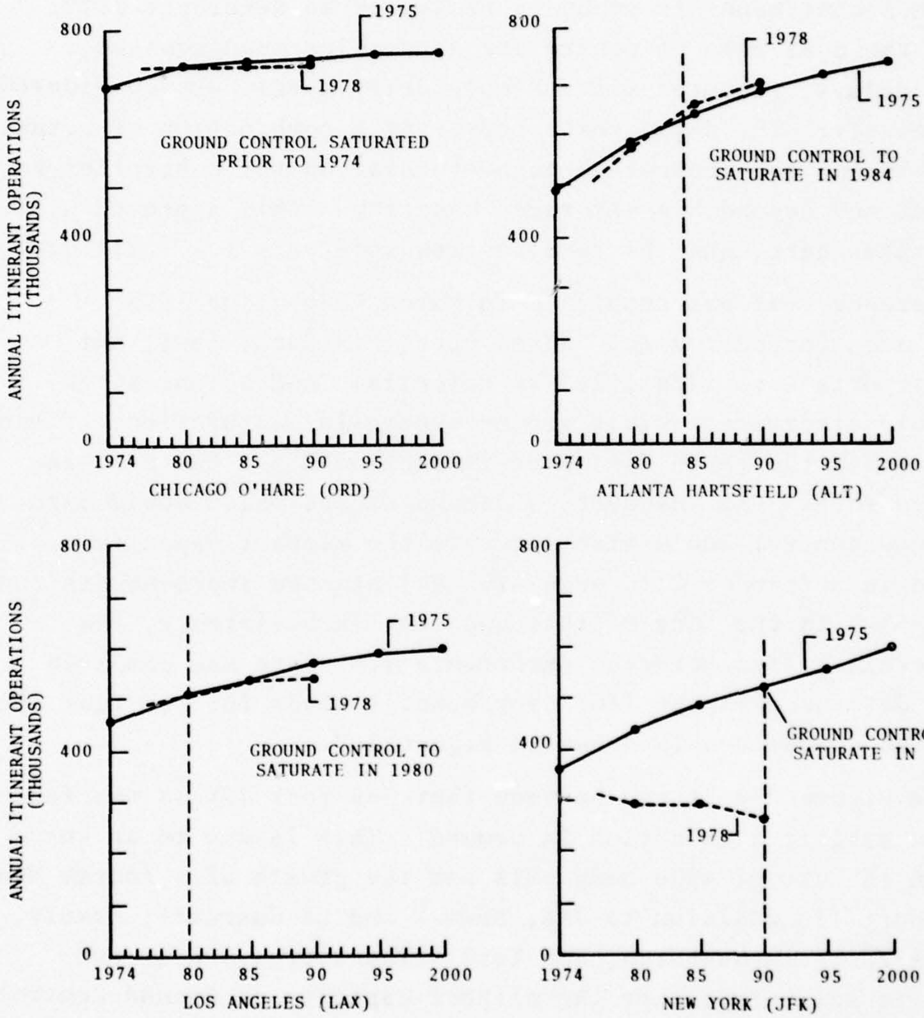


FIGURE 2-7. TERMINAL AREA FORECAST COMPARISON

The estimated delay associated with Ground Control saturation at the three candidate airports is shown in Figure 2-8. This delay is taken from Reference 1.17 and is based upon the 1975 forecast data. It can be seen that by the mid-1980's all three airports are accruing substantial delay costs. Even if Chicago and Los Angeles demand should level off in 1985 as shown in Figure 2-7, and Atlanta should level off in 1990, the average annual delay costs over the three airports would be \$1.5 million (1975 dollars). Adjusting these costs to account for an inflation rate of 5 percent per year yields \$1.8 million in 1978 dollars.

These costs can be translated into constraints on the cost of a new system (e.g., TAGS) which would reduce or eliminate the delays. Based upon Reference 1.17, it is assumed that annual operating and maintenance costs are approximately 9 percent of the initial capital costs (I) which include basic equipment, transportation to the site, installation, and commissioning costs. Then, amortizing initial capital costs (I) and development costs (D) over 15 years at a 10 percent discount rate, spreading development costs over the three systems, and adding operating and maintenance costs, an expression for annual system costs can be developed. The equation is:

$$\text{Annual system costs} = .22\ I + (.13/3)D. \qquad (1)$$

For a system to be cost beneficial (B/C>1) it must, therefore, satisfy the equation

$$\$1.8\ \text{million}/(.22I + .04D) > 1. \qquad (2)$$

This is depicted in Figure 2-9. The high system related costs allowable reflect the large payoff available to such a system.

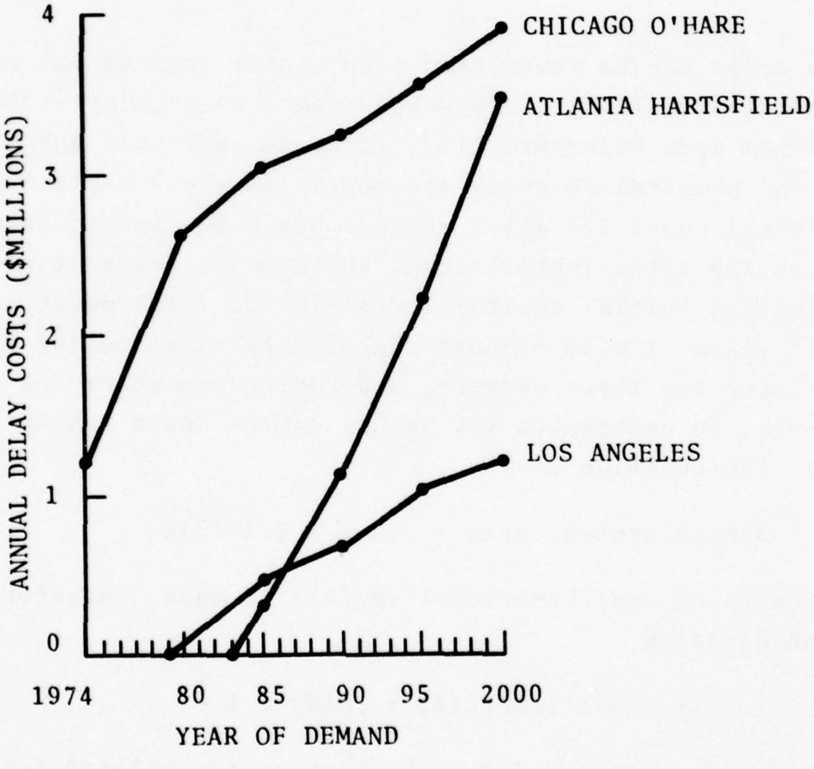


FIGURE 2-8. ANNUAL DELAY DUE TO GROUND CONTROL SATURATION IN BAD CAB VISIBILITY (1975 DOLLARS)

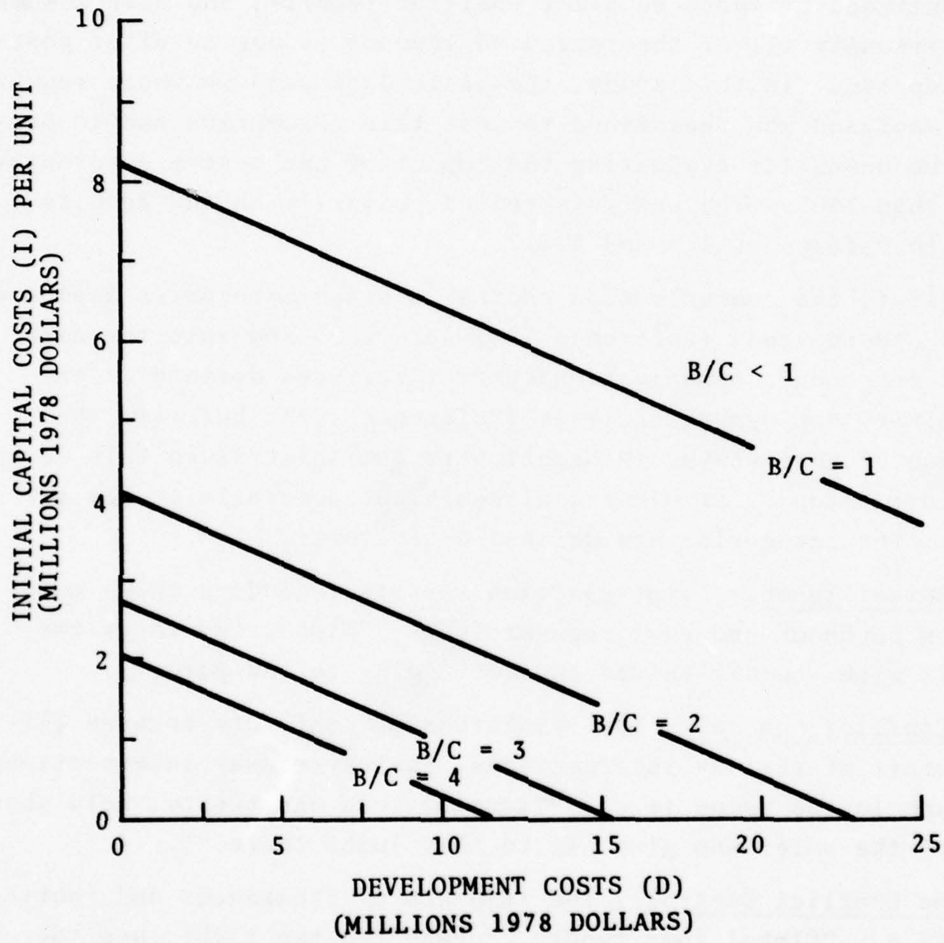


FIGURE 2-9. BENEFIT/COST CURVES FOR A SYSTEM WHICH ELIMINATES THE DELAY CAUSED BY GROUND CONTROL SATURATION IN BAD CAB VISIBILITY AT THREE SITES

2.1.3 The Cause of Ground Control Saturation During Bad Cab Visibility

ASTC requirements analyses to-date have measured the increased channel loading in bad cab visibility conditions, have identified the continued reliance on pilot position reports, and have assumed that virtually all of the increased loading is due to pilot position reports. In this study, the basic data used in those requirements analyses was reexamined to test this assumption and to provide the means for evaluating the impact of new system alternatives other than TAGS. The analysis relied primarily on the results given in References 1.3 and 1.8.

First, the communication channel message categories employed in the O'Hare study (Reference 1.8) were combined into the categories of ground communication/control services defined in the preliminary deployment analysis (Reference 1.3), but with the addition of gate status information transmission since this is an important category at O'Hare, although not generally at all airports. The categories are defined as follows:

Surveillance - Pilot position reports including those made on pushback and taxi request (e.g., "Global two forty two is with you off thirty two left going to the gate.").

Conflict Control - The resolution of conflicts between aircraft at taxiway intersections, taxiway/runway intersections, and in the ramps (e.g., "TransAmerican one twenty, hold short of the outer and give way to that jumbo there.").

No Conflict Control - The issuance of clearances and routing (e.g., "Global four twenty, runway two two right, use the inner to Tango, then transition to the outer and hold short of Echo.").

Gate Status - Delivery of gate assignment and any expected delay to Ground Control. This applies only to arrivals (e.g., "...going to Gate E five and we've got a ten minute gate delay.").

Other - General information and advisories which are not covered by the above four categories. This includes runway conditions, wait time if there is a departure queue, and weather, if it is not current on ATIS.

The O'Hare study data was then used to provide the breakdown of communication/service time provided on the average to each aircraft. The results are depicted in Figure 2-10 for two ground controllers. The source data is given in Table A-3 of Appendix A.

From Figure 2-10 it can be seen that the average service time per aircraft increases from 24.7 seconds in good cab visibility to 50.9 seconds in bad cab visibility. Using the average service time, the saturation capacity estimate can be made. Reference 1.8 estimates that a controller will be required to talk continuously for at least 5 minutes each hour if the average hourly communication load is 60 percent (or 2160 seconds per controller during the hour). The saturation capacities are then 2160*2/24.7=175 operations/hour in good cab visibility, and 2160*2/50.9=85 operations/hour in bad cab visibility.

Also seen in Figure 2-10, the largest single service category responsible for the increase in average service time is surveillance through the increased use of pilot position reports. However, this category is responsible for only half of the total increase. The remaining increase is spread about evenly among conflict control, no conflict control, and other. While improvements in surveillance offers the largest payoff area, some payoff is available in the three other service categories.

The four categories will be used to define improved system concepts and to evaluate their potential benefits. The system objectives will be to reduce the average service time required per aircraft, thus restoring lost capacity and reducing the associated delay.

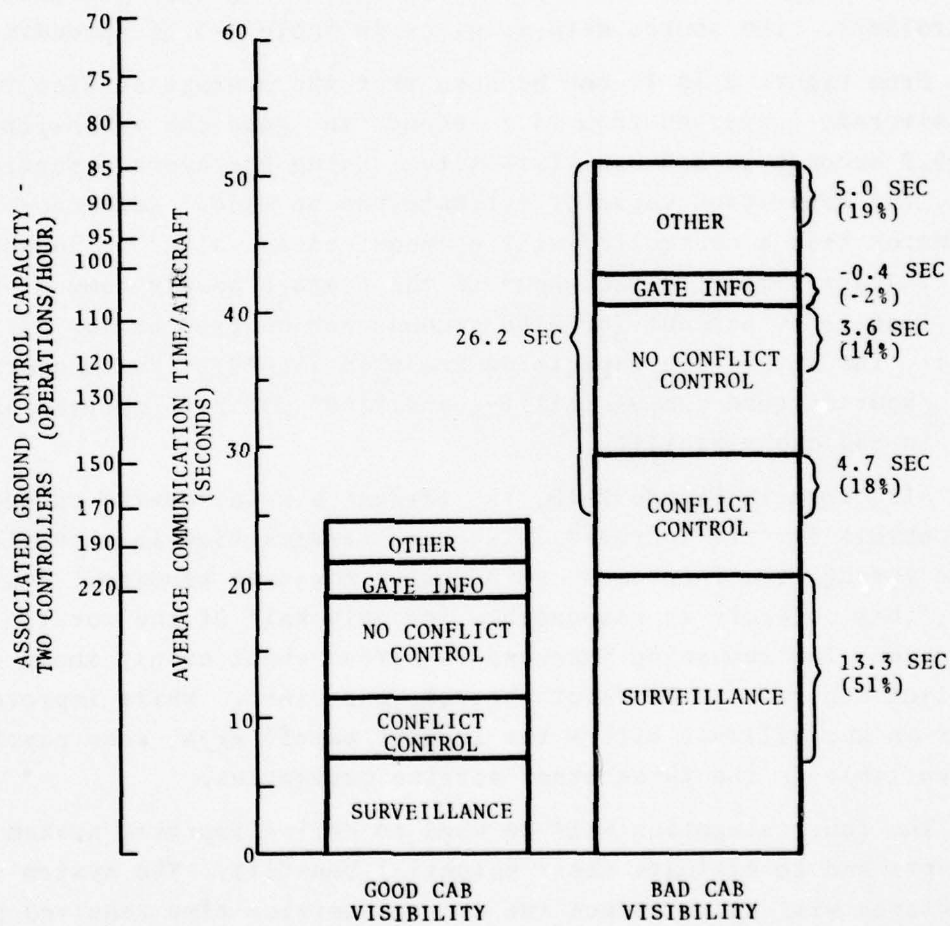


FIGURE 2-10. BREAKDOWN OF COMMUNICATION LOAD INCREASE FOR TWO GROUND CONTROLLERS IN BAD CAB VISIBILITY (WITH ASDE)

2.2 CAPACITY AND PRODUCTIVITY

While Ground Control capacity with two ground controllers is generally adequate under good visibility conditions, the installation of new systems to eliminate control positions can be traded off against controller costs.

In Reference 2.5 it is estimated that ground controller saturation would require the regular staffing of a second ground controller when an airport's demand reached 464,000 annual itinerant operations. Using the latest Terminal Area Forecast data (Reference 2.4) this would mean that by the late 1980's, about ten airports would staff two ground controllers on a regular basis (i.e., for the two busy shifts). A list of the ten airports is given in Table 2-2. If at those ten airports something could be done to aid the first ground controller and eliminate the need for the second controller, a net benefit might be realized.

TABLE 2-2. TOWERS FORECASTED TO USE TWO GROUND CONTROLLERS ON A REGULAR BASIS

TOWER	FY 1990 ANNUAL ITINERANT OPERATIONS (THOUSANDS)
Chicago O'Hare Intl, IL	740
Atlanta Intl, GA	700
Los Angeles Intl, CA	537
Denver Stapleton Intl, CO	560
Dallas Ft. Worth Regional, TX	577
Van Nuys, CA	478
Phoenix Sky Harbor Intl, AZ	498
Pittsburgh Greater Intl, PA	508
Memphis Intl, TN	486
Honolulu, HI	483

From the list it is seen that the airports will be level IV or V. Therefore, a controller cost estimate was made based upon a medium step (step 04) GS-13 controller with 10 percent added to cover benefits. The savings estimate is $31,500 per year per shift for two shifts for a total annual savings of $63,000. As was done in Section 2.1.2, this savings can be translated into constraints on the cost of a new system which would eliminate the second ground control position. For the system to be cost beneficial (B/C>1) it would have to satisfy the equation

$$\$63{,}000/[.22I + (.13/10)D] > 1. \qquad (3)$$

This is depicted in Figure 2-11. The potential gains are far less than those associated with delay so that allowable system costs are much less.

2.3 SAFETY

2.3.1 Summary

Of 290 aircraft-to-aircraft collisions taking place on the surface of domestic airports during calendar years 1964 to 1976, 93 occurred at airports having an operational ATC Tower at the time of the accident. A study of the National Transportation Safety Board (NTSB) briefs of these 93 accidents reveals that 27 percent (25) took place at the top 25 air carrier airports (greater than 100K annual air carrier operations). This same class of airports accounted for 87 percent of the estimated accident cost and 76 percent (13) of the fatalities (refer to Table 2-3). Table 2-4 shows the unit costs used in estimating accident costs.

The potential for deploying any system intended to prevent accidents was determined by dividing the estimated accident cost attributed to a particular class of airport by the number of airports in that class. Applying the rationale developed in Section 2.1.2, the maximum initial capital cost per installation, that would be offset by the $66,000* average annual good weather accident benefits attributed to the top 25 air carrier airports

*All cost figures reflect 1978 dollars unless otherwise noted.

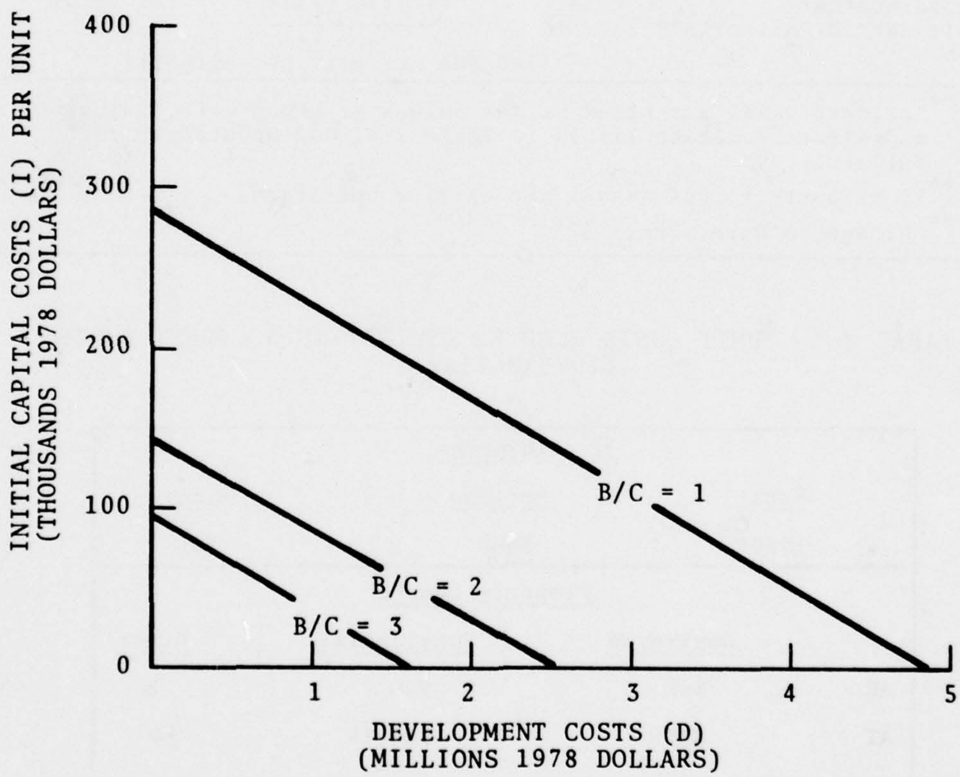


FIGURE 2-11. BENEFIT/COST CURVES FOR A SYSTEM WHICH ELIMINATES THE NEED FOR TWO GROUND CONTROLLERS AT 10 SITES

TABLE 2-3. AIRPORT SURFACE ACCIDENT SUMMARY
ATC TOWERED AIRPORTS 1964-1976

Category	Number of Accidents	13 Year Cost*	Fatalities
All	93	$40.3M (100%)	17 (100%)
Air Carrier Airports**	25	$35.2M (87%)	13 (76%)
Bad Visibility Due to Weather	1***	$13.7M (34%)	10 (59%)
Good Weather	92	$26.6M (100%)	7 (100%)
Good Weather-Air Carrier Airports**	24	$21.5M (81%) [$66,000 per year per airport]	3 (43%)

*Accident costs are based on the values of human life, injuries, and aircraft damage listed in Table 2-4, and updated to 1978 dollars.

**25 airports > 100K annual air carrier operations

***Chicago, O'Hare, Dec. 1972.

TABLE 2-4. UNIT COSTS USED IN ESTIMATING ACCIDENT COSTS (1975 dollars)

Injuries		
Fatal	Serious	Minor
$300K	$60K	$2K

Property Damage	Destroyed	Substantial	Minor
AC	$6M	$2M	0
AT	$200K	$66.7K	0
GA	$50K	$16.7K	0

is $304,000.* The per-airport initial capital cost rapidly diminishes for wider deployments (i.e., to small airports) because the diminishing incremental accident cost is spread over a rapidly increasing number of airports.

Commercial aviation accounted for a disproportionate share of the accident loss in terms of dollars and human injury considering the percentage of accidents involving air carrier aircraft.

Thirteen year costs for accidents occurring during good cab visibility conditions at the three TAGS candidate sites (ORD, LAX, and ATL) are estimated at $3.6 million, resulting in a maximum allowable (for B/C=1) initial capital investment of $428,000 per site for TAGS enhancements which might have prevented such accidents.

These results indicate a potential for justifying ATC system improvements based on safety benefits alone for the major air carrier airports, particularly the TAGS sites. Further study of the NTSB files is needed to classify better the accidents with regard to cause and location on the airport surface. Only then can the benefits expected from specific system improvements be used to justify their added cost.

2.3.2 Safety Aid Deployment Potential

Accidents involving commercial aviation dominate the loss statistics from both the accident cost and personal injury standpoints. Table 2-5 reveals that while only 34 percent of the airport surface accidents sampled involved one or more air carrier aircraft, the same accidents account for 89 percent of the total cost and 76 percent (13 out of 17) of the fatalities.

Table 2-6 focuses on the group of accidents which took place at the major air carrier airports. The 25 accidents in Table 2-6 account for 87 percent of the estimated cost of the 93 accident sample. The heavy toll (measured both in cost and fatalities) due

*All cost figures reflect 1978 dollars unless otherwise noted.

TABLE 2-5. ACCIDENTS INVOLVING ONE OR MORE AIR CARRIER AIRCRAFT

	Number of Accidents	Cost*	Injuries Fatal	Serious
Top Air Carrier Airports	21	$35M	13	11
All Other Airports	11	$ 1M	-	-
Total of above	32	$36M	13	11
% of All Accidents	34%	89%	76%	92%

*1978 Dollars.

TABLE 2-5. ACCIDENTS INVOLVING ONE OR MORE AIR CARRIER AIRCRAFT

	Number of Accidents	Cost*	Injuries Fatal	Injuries Serious
Top Air Carrier Airports	21	$35M	13	11
All Other Airports	11	$ 1M	-	-
Total of above	32	$36M	13	11
% of All Accidents	34%	89%	76%	92%

*1978 Dollars.

TABLE 2-6. ACCIDENTS AT AIRPORTS WITH MORE THAN 100K ANNUAL AIR CARRIER OPERATIONS

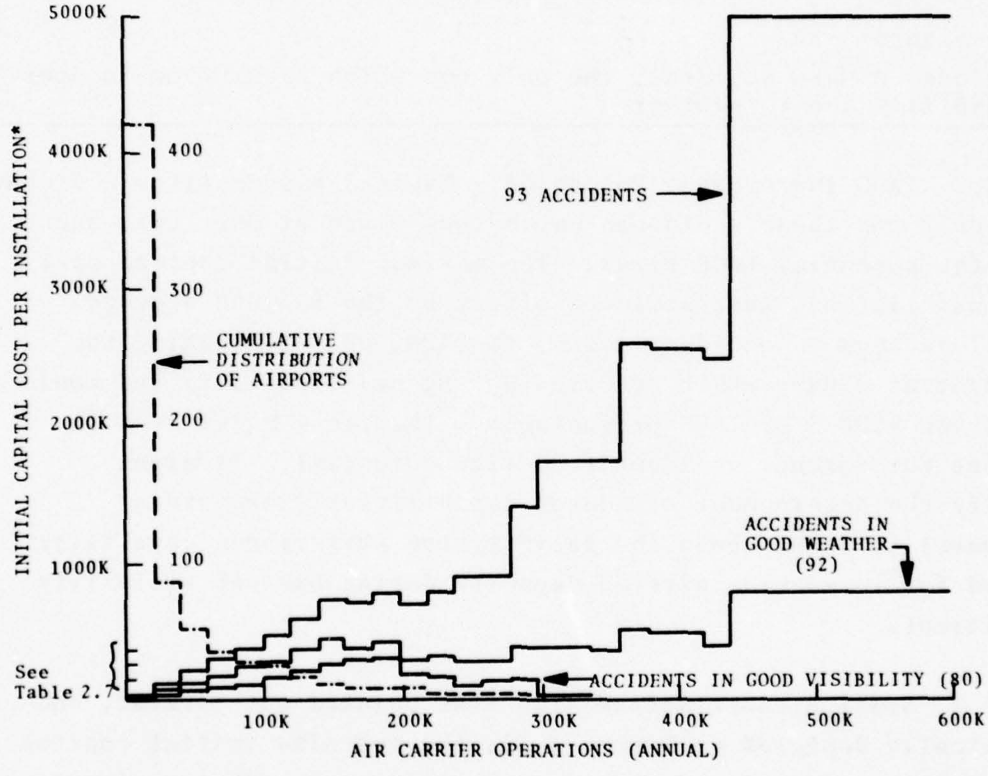
Location	Date	Visibility	Cost	Aircraft/Injuries		Factors
ORD	5-08-69	Night	$ 2,492K	AC/AC	•	ATC implicated
ORD	11-24-72	Night	135	AC/AC	•	ATC "
ORD	12-20-72	Night/fog	13,681	AC/AC	10F 9S	ATC "
LAX	1-12-70	Night	393	AC/AC	•	
LAX	4-06-73	Night	205	AC/GA	•	
LAX	12-24-76	Night	171	AC/AC	•	ATC implicated
JFK	9-23-65	Night	122	AC/GA	•	ATC "
JFK	6-06-64	Day	48	GA/GA	•	
JFK	11-21-74	Day	2,436	AC/AC	•	Airport Construction
LAX	6-09-64	Twilight	200	AC/GA	•	
ATL	5-12-67	Day	27	GA/GA	•	
SFO	11-21-76	Night	285	AC/GA	•	
LGA	5-06-75	Day	188	AC/AC	•	
DCA	5-14-69	Day	2,589	AC/AC	•	Misjudged Wingtip Clearance
LGA	5-01-67	Day	1,499	AC/GA	3F 2S	Radio Out
SFO	11-20-64	Day	169	AC/AC	•	
PHL	11-06-69	Night	155	AC/AC	•	
EWR	2-27-67	Day	2,414	AC/AC	•	Ramp Crew Blamed
EWR	3-14-67	Day	2,627	AC/AC	•	" " "
DTW	4-04-70	Night	87	AC/GA	•	
BOS	5-26-66	Day	121	AC/GA	•	
CLE	9-06-68	Twilight	4,858	AC/AC	•	Misjudged wingtip Clearance
SJU	2-12-70	Day	215	AC/AC	•	
HON	2-26-68	Night	27	Mil/GA	•	ATC implicated
HON	2-28-74	Day	29	GA/GA	•	ATC implicated
		Total $35.2 million				

to accidents at the major air carrier airports logically leads to the consideration of deploying ATC system improvements only at that select group of airports.

2.3.2.1 Initial Capital Cost - Figure 2-12 is a plot of initial capital costs for a deployment made as a function of annual air carrier operations. The curves are obtained by dividing the estimated accident cost from the 13-year data sample by the number of airports having the same annual air carrier activity (e.g., the value of the plot at 100,000 operations is computed by dividing the costs for those accidents taking place at airports having >100K ops by the number of CONUS airports having >100K ops). Initial capital cost is computed assuming a 15 year useful life at a 10 percent cost of capital, with O & M estimated as 9 percent of capital cost. Engineering and development (E & D) costs are not included in this plot because of the preliminary nature of this study. It is believed that E & D cannot be estimated until a specific type of system improvement is selected based on further study of the accident data, perhaps in conjunction with transgression data.

The two lower plots of Figure 2-12 result from the subtraction of accident costs for those accidents which could be argued as being ASDE (or TAGS) preventable. Because the top air carrier airports are receiving ASDE-3 or TAGS for capacity improvement reasons, it could be contended that accidents taking place at night/twilight and in poor visibility due to bad weather would be prevented by those systems.

Table 2-7 lists the initial capital cost and annual savings for a deployment to the top 25 airports for each class of accident. Cost per installation ranges from a low of $176K to a high of $499K. The benefits (i.e., costs estimated preventable) applicable to a non-ASDE TAGS ATC improvement probably lie within that region because preliminary inspection of the accident data indicates that night/twilight accidents are not necessarily ASDE preventable, some having taken place at ASDE-2 sites.



*Development Costs = 0, costs in 1975 dollars.

FIGURE 2-12. INITIAL CAPITAL COST PER INSTALLATION (DEPLOYMENT BASED ON AIRLINE OPERATIONS)

TABLE 2-7. INITIAL CAPITAL COST FOR A DEPLOYMENT TO THE TOP 25 AIR CARRIER AIRPORTS

Class of Accidents	Annual Savings	Initial Capital Cost* Per Installation
All Accidents	$108K	$499K
Accidents in Good Weather**	$ 66K	$304K
Accidents in Daylight	$ 38K	$176K

*See Figure 2-12.
**Excludes O'Hare accident, the only one which took place in poor visibility due to weather.

2.3.2.2 TAGS Improvement Potential - Table 2-8 summarizes accident data only for those accidents which took place at ORD, LAX, and ATL, the potential TAGS sites. The maximum initial capital cost per installation, that would be offset by the $93,000 average annual savings in accident costs, is $428,000, eliminating the accident at O'Hare which occurred during bad visibility and would have been ASDE-3 or TAGS preventable. This is a major area to examine for further accident reduction potential. It might justify the development of add-on capabilities (hardware or software) to TAGS, above the basic system performance capability needed for increasing airside capacity during bad cab visibility conditions.

2.3.2.3 Small Airport Safety Aids - As pointed out earlier, and graphically depicted on Figure 2-12, the per-site initial capital cost drops rapidly for deployments beyond the top 25 air carrier airports. For example, if a system or systems were deployed to the top 60 air carrier airports (>50,000 annual air carrier operations), the initial capital cost drops to less than $150K per airport for the good weather accident base, about half of the $304K (see Table 2-7) found for the 25 airport deployment. This magnitude of initial capital cost begins to look quite small, especially considering the fact that E & D costs are not included,

TABLE 2-8. ACCIDENT COSTS AT TAGS CANDIDATE SITES

Site	Date	Cost (1978 dollars)	Fatalities
ORD	5-08-69	$ 2,492K	-
"	11-24-72	135K	-
"	12-20-72*	13,681K	10
LAX	1-12-70	393K	-
"	4-06-73	205K	-
"	12-29-76	171K	-
"	6-09-64	200K	-
ATL	5-12-67	27K	-

All accidents: $17,304K

Good Weather Only: $3.62 Million

$$\frac{\$3.62M}{13 \text{ years} \times 3 \text{ airports}} = \$93{,}000 \text{ annual savings per airport}$$

*Bad visibility due to weather.

and the uncertainty concerning the applicability of common solutions to each airport in the deployment.

The safety benefits for smaller air carrier airports (i.e., those below 100,000 annual air carrier operations) can be examined by subtracting the accident costs for the top 25 airports from the total. The resulting amount, $5.1 million, is distributed among a large number of towered airports (300 to 400 depending upon the year assumed).

Table 2-9 shows that even if it is optimistically assumed that the majority of the benefits could come from as few as 50 airports (which is not the case in the actual data), the per-airport initial capital cost in only $36,000. A single safety aid such as a low cost ASDE (not justified on the basis of capacity improvements) with an estimated cost of $200,000 per system could be installed at only nine airports, applying the same $5.1 million in benefits. This ignores the fact that the ASDE may only be able to prevent accidents in nondaylight visibility conditions, which is a considerably smaller set of accidents. It is difficult to argue the merits of further study of a low cost safety improvement for the smaller air carrier airports strictly based on the historic accident data studied herein.

TABLE 2-9. DISTRIBUTION OF $5.1 MILLION IN BENEFITS AMONG SMALL AIR CARRIER AIRPORTS

Number of Airports	Per Airport: Per Year Savings	Per Airport: Initial Capital Cost
10	$39K	$181K
50	8K	36K
100	4K	18K
200	2K	9K

2.3.3 Accident Characteristics

The 93 accidents at towered airports have been characterized by time of day, type of lighting and visibility, location by airport, and location on the airport surface as an aid in determining causal factors.

2.3.3.1 Visibility and Time of Day - In the NTSB briefs of the 93 accidents occurring at towered airports, only one listed poor visibility due to weather as a factor: the December 1972 O'Hare collision that resulted in 10 fatalities and destroyed one air carrier aircraft. Weather was definitely a factor in that accident and, had a properly operating ASDE been utilized to determine the taxiing aircraft's position, the accident could have been prevented.

Figure 2-13 shows the distribution of accidents by time of day for the total sample (93 accidents), the 16 runway accidents, and the 25 accidents that took place at the top air carrier airports. The first two plots (2-13 a and b) show the double-humped characteristic typically seen in airport daily traffic with morning and evening rush hours. This confirms the intuitive conclusion that accidents tend to be a function of the traffic density at any given airport.

The 25 accident distribution, however, shows a pronounced peak from 6 to 8 pm, indicating a correlation between accident frequency at major airports and nonideal natural lighting conditions. The reported time of accident was used in conjunction with the Farmer's Almanac to determine the natural lighting conditions at the time of accident. Table 2-10 shows the distribution of accidents between ideal (day) and nonideal (night and twilight) conditions for each of the three classes of accidents discussed above. Included is a sample of Boston Logan daily traffic. The 25 air carrier airport accidents definitely show a bias towards occurring in night/twilight conditions. Half of the accidents took place in nonideal lighting conditions when typically 1/4 to 1/3 of the traffic activity occurs.

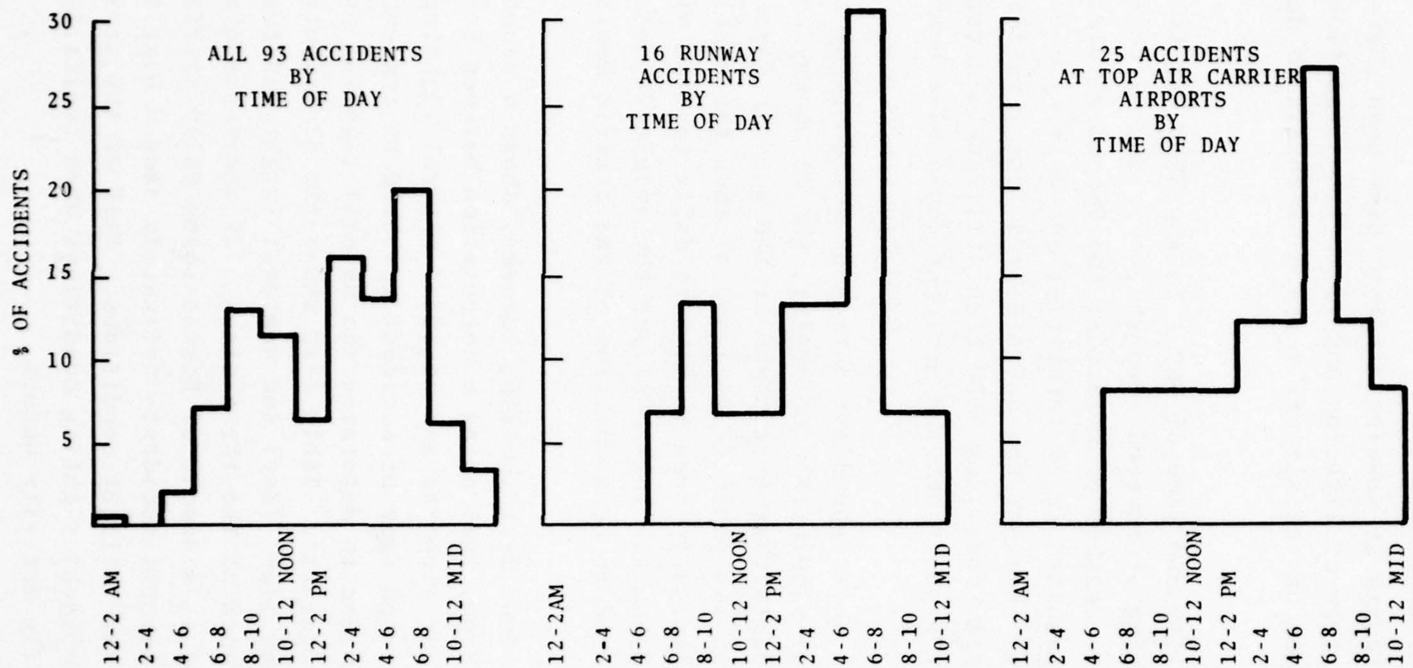


FIGURE 2-13. ACCIDENTS BY TIME OF DAY

Without going into the specifics of each accident, this indicated correlation suggests the need for improved pilot and controller visibility at major airports in nondaylight hours. The 16 accident runway sample also suggests that nonideal lighting conditions more adversely affect pilots and controllers in aircraft landing and takeoff situations which involve higher speeds. Taxiway and other nonrunway accidents take place at lower speeds and are probably more congestion related than visibility related.

TABLE 2-10. ACCIDENT OCCURRENCE AS A FUNCTION OF DAYLIGHT CONDITION

	Day	Night, Twilight
All 93 Accidents	76%	24%
16 Runway Accidents	56%	44%
25 Accidents at Top Air Carrier	50%	50%
Logan Sample* (Daily Traffic)	74%	26%

*Assumes day = 6 am to 6 pm annual average

2.3.3.2 Accident Frequency per Airport - The NTSB data was reviewed for any unusual clustering of accidents at one airport which could reveal a trend, or indicate an historic problem which already may have been solved. Only two such accidents were found, taking place at Newark within one month of each other in 1967, both due to congestion and poor ramp guidance. Sixty-three accidents took place at airports having only one accident in the 13-year period. The 63 airports represent 84 percent of the 75 airports in the sample. The distribution of accidents among airports is shown in Figure 2-14.

Seven of the 12 multiple accident airports are major air carrier airports, accounting for a similar proportion of the accidents (18 out of 30 accidents). All but 1 of the 12 airports are

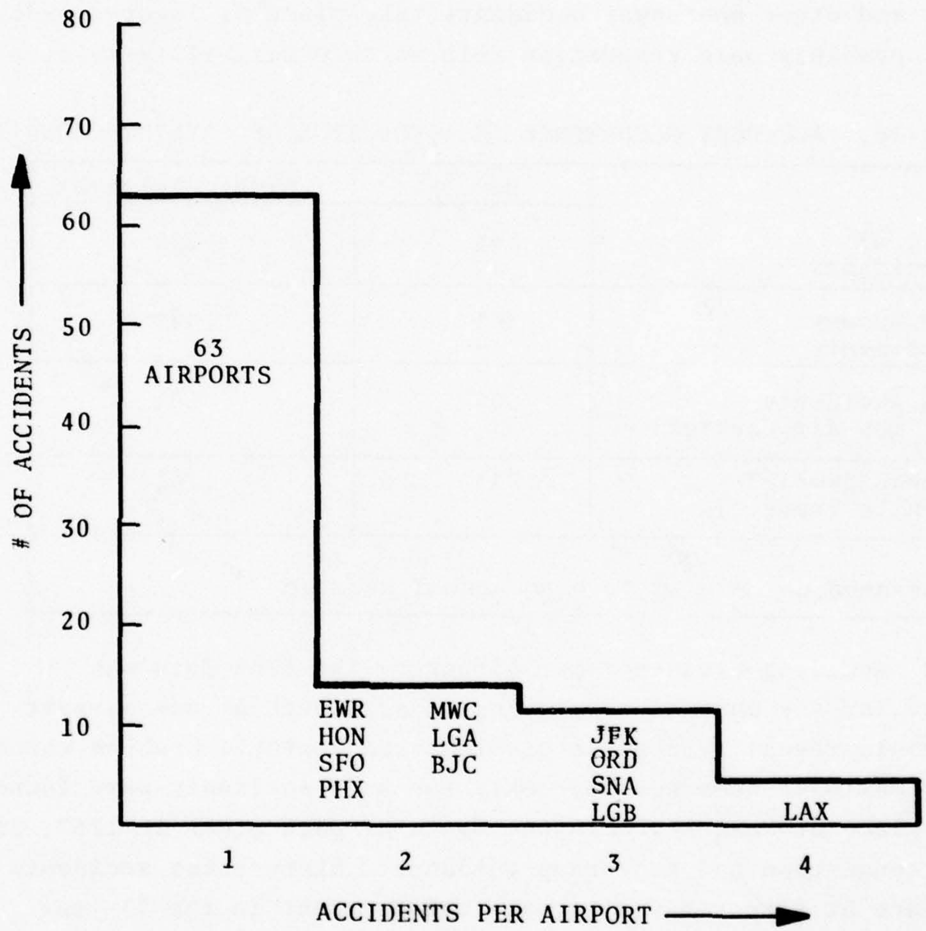


FIGURE 2-14. DISTRIBUTION OF ACCIDENTS BY AIRPORT

considered high activity airports with greater than 100,000 total annual aircraft operations. LAX has the unique distinction of having four accidents. The accidents at LAX took place in 1964, 1970, 1973 and 1976, on different parts of the airport. With the exception of the Newark accidents already discussed, the other multiple accidents were well spaced in time (by an average of 5 years) or by location on the airport.

It is concluded that the 93 accident sample is representative of today's environment, with no trends clearly pointing to a set of "hot spots" or unique problem airports.

2.3.3.3 Location on the Airport Surface - The distribution of accidents over various portions of the airport surface is shown in Table 2-11.* Accidents do not appear to be concentrated on any particular area of the airport. Based on the fact that higher speeds are involved in runway and taxiway/runway intersection operations, the areas are divided into two classes: 1) high risk movement areas where a collision probably involves fatalities and aircraft destruction, and 2) congestion related areas where collisions between slower moving traffic cause minor damage. The cost and human loss statistics tend to support the above classification as seen in the table, with 6 of the 7 fatalities and a disproportionately high share of the cost relative to accident frequency occurring in the high risk area. The share of air carrier accidents at the major airports is roughly proportional to the accident frequency between the two classes with 7 out of 20 (35%) air carrier accidents taking place in the high risk area compared with 25 of 92 (27%) for all type aircraft and airports.

*The December 1972 runway accident at Chicago O'Hare has been excluded so that the extremely high cost of this accident would not bias the cost percentages.

TABLE 2-11. ACCIDENTS CHARACTERIZED BY LOCATION ON AIRPORT SURFACE

Category	# Accidents	% Cost	Fatalities	# Accidents Involving at Least 1 Air Carrier/Taxi*
High Risk Areas				
o Runway	6	8	4	2
o Runway/Taxiway Intersections	10	4		3
o Taxiway Intersections	9	30	2	2
Subtotal:	25	42		
Congestion Related				
o Taxiway (All other)	37	24		5
o Runup Area	17	12		3
o Ramp Area	13	22	1	5
Subtotal:	67	58		
Total	92	100	7	20

*At top air carrier airports.

The large category called taxiway (all other) reflects the lack of description in the NTSB briefs. A study of the complete accident reports would undoubtedly result in the reclassification of some of the 37 accidents listed in this category.

2.3.3.4 Cause - While no attempt was made to investigate accident reports beyond the cryptic discussion in the NTSB briefs, the following accident causes are noted for the 93 accidents, listed in order of frequency:

- o Pilot Error
  - Failure to see and avoid
  - Misjudged aircraft boundary clearance
- o ATC Error
  - No traffic advisory
  - No/improper control instructions
- o Facilities
  - Taxiway construction
  - Pavement quality
- o Equipment failure

In clear weather conditions, 11 accidents took place (12%) which were partially or totally blamed on ATC, for a total cost of $4.4 million (17% of total cost for 92 accidents). Six of these took place at major air carrier airports. The historic accident data indicates that the quality of ATC has an influence on safety, but is not the dominant cause for accidents in the 13-year period.

2.4 EQUIPMENT LIMITATIONS

2.4.1 ASDE

As a result of the increased deployment established for ASDE, an all-new ASDE must be procured, as the 20-year-old ASDE-2 cannot be reprocured. In addition, basic limitations in ASDE-2

performance require the development of ASDE-3. The major reasons for the replacement of ASDE-2 are:

a. ASDE-2 was built with vacuum tube technology. Although its reliability has been increased by a modification program, the system is not inherently as reliable as a modern solid state electronic system, and replacement parts availability is a problem.

b. ASDE-2 does not perform adequately in medium to heavy precipitation during which the airport is still operating. Coverage is restricted due to:

   o Excessive RF path attenuation by precipitation in the 24 GHz frequency band, producing "blackout" beyond 1-1/2 miles (i.e., loss of targets).

   o RF backscatter radiation from precipitation particles at 24 GHz, causing display clutter at short ranges, or "whiteout."

   o Increased attenuation from radome rain sheeting and water absorption.

c. The lack of target detection capability in rainfall combined with the high RF attenuation of the 24 GHz waveguide restricts the variety of installation configurations available. Tower cab installations where the radar equipment is not located immediately beneath the antenna pedestal cannot be accommodated without serious loss in performance. The considerable weight and wind-induced overturning moment of the rooftop equipment also limits installation flexibility.

ASDE-3 is a solid state, 16 GHz frequency band radar with the following features:

a. Solid state electronics and built-in test capability to improve greatly reliability and maintainability.

b. Reduced RF attenuation and backscatter effects at 16 GHz, a lower receiver noise figure, use of frequency agility,

reduced waveguide loss, and better antenna beamshape combine to produce greatly improved target detection performance in precipitation.

c. An integral antenna-rotodome reduces rooftop weight and aerodynamic cross section, allowing installation on a greater variety of tower cabs.

The ASDE-3 will also have the capability to suppress unwanted ground clutter on the display by means of a digital display enhancement unit (DEU). Map lines of controller-selected intensity are digitally synthesized, defining the boundaries of the critical airport areas as shown in Figure 2-15.

The map produced will be operationally superior to the display of actual ground clutter, allowing the ground controller to detect more readily targets on taxiways. The controller can independently adjust the brightness of map line, target, and background (ground clutter) videos to provide an optimal display

2.4.2 Tower Cab Blindspots and Closed Circuit Television

Many airports have a tower cab blind spot problem to some degree. This is usually due to the obstruction of the cab's view of the airport surface by airport buildings, but also includes situations where distance and/or terrain cause a part of a taxiway or runway to be difficult or impossible to see. The problem is sometimes solved by removing the obstruction or raising the tower. However, when neither of these solutions is practical and the problem is serious enough, other attempts at solving the problem have been considered. An experiment at New York's Kennedy Airport with a loop display system (using inductive loops to sense aircraft on taxiways) proved unsuccessful. However, closed circuit television (CCTV) has been used at several airports to solve the blind spot problem with some amount of success.

A survey was made of airport tower use of CCTV for blind spot and related problems. As shown in Table 2-12, two airport towers were found to be using CCTV at present. Honolulu International uses CCTV for a taxiway blind spot caused by a concourse.

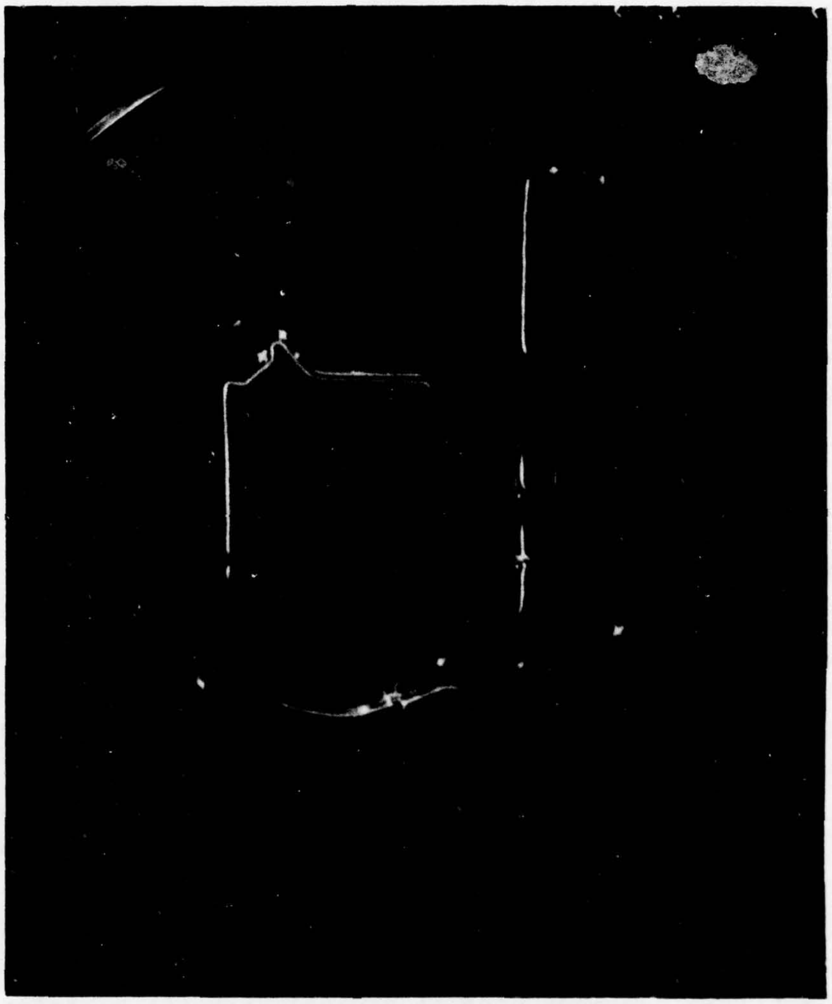


FIGURE 2-15. ASDE-3 MOCKUP

TABLE 2-12. PRESENT AIRPORT TOWER USE OF CCTV

AIRPORT	PERIOD OF USE	PURPOSE	COVERAGE AREA	STATUS
Honolulu International	March 1977 to Present	To see behind a concourse which was built by the airport	Intersection of several taxiways	In use However, FAA continues to publicize coverage area as nonvisible from tower
Boston Logan International	June 1978 to Present (1976 to 1978 experimentally)	To see if ships passing the end of a runway are tall enough to require landing mimumums to be raised	Ship channel on both sides of runway end	In use Upgraded system using additional cameras is planned

The airport installed the system and maintains it. (The FAA did not fund the project since the obstruction was due to airport construction.) Maintenance is performed by a state contractor. Two cameras are used, each aimed at a little more than half of the target area, which is a complex taxiway intersection. There seems to be mixed reaction on the usefulness of the system, and the FAA continues to publicize the coverage area as nonvisible from the tower.

Boston Logan International Airport does not have a blind spot problem, but it using CCTV for a related purpose. The main Boston ship channel passes directly across the end of a runway. If the height of a ship passing the end of the runway is above 85 feet, then the landing minimums must be increased (from DH216/RVR2400 to DH424/RVR4000). Logan tower controllers can ascertain the existence of ships passing the runway by ASDE, but cannot reliably estimate ship height by ASDE or visual sighting. To prevent diversions and flight cancellations due to the higher minimums, the airport (with full FAA cooperation) installed a CCTV system. This system allows the tower to look at the ship channel and, using a cursor set at 85 feet, to determine the height of passing ships. Maintenance is provided by an airport contractor. One camera (with a backup camera) is presently used to look at the channel after a ship has been seen on ASDE. Present plans are to expand the system to four sites, so that ships can be seen from closer positions and more in advance of their passing the runway. As evidenced by the plans to expand it, the system is considered to provide a useful service--at least in certain weather conditions.

Table 2-13 shows eight airports where CCTV has been used in the past. In five airports (Gregg County, Shreveport Regional, Detroit Metropolitan, Atlanta Hartsfield International, and New York LaGuardia) the CCTV system acted as a temporary fix for a blindspot problem that was eventually eliminated by other means. In two airports (Salt Lake City Municipal and Los Angeles International) the CCTV system did not perform well enough in alleviating blind spot problems to justify the cost, and it was removed.

TABLE 2-13. PAST AIRPORT TOWER USE OF CCTV

AIRPORT	APPROXIMATE PERIOD OF USE	PURPOSE	COVERAGE AREA	REASON DEACTIVATED
Longview TX Gregg County Airport	1972 to 1977	To see behind a hanger	A runway and a taxiway	New tower built
Shreveport Regional	1972 to 1976	To see behind a new terminal building	Part of a taxiway and a ramp area	New tower built
Detroit Metropolitan	1972 to 1975	To see behind the elevator shaft of a hotel	Aimed up ILS final approach course for a runway	New tower built
Greater Buffalo International	1973 to 1975	To see behind part of terminal building	Runup area for a runway	Removed at FAA request due primarily to poor reliability. Now have NOTAM saying that area cannot be seen from tower.
Salt Lake City Municipal	1969 to 1972	To see runway and taxiways distant from tower	Parts of a runway and some taxiways	Usefulness of system did not justify cost
Los Angeles International	1963 to 1969	To see runways in reduced visibility	Approach end of two runways	Usefulness of system did not justify cost
Atlanta Hartsfield International	1965 to 1967	To see behind homes and buildings	Part of a runway	Obstructing houses and buildings bought and destroyed
New York LaGuardia	1962 to 1964	To see behind building	Part of a runway	New tower built

In the remaining airport, Greater Buffalo International, the FAA requested that the airport remove the CCTV system. This was due primarily to the poor reliability of the system and to the problems caused when the system was not operable but the pilots assumed that it was. Presently, a NOTAM describes the area formerly covered by the CCTV system as a blind spot.

Users of the systems listed in Tables 2-12 and 2-13 have a mixed reaction to the utility of a CCTV system. General comments ranged from "very satisfactory" to "not very effective" and "created more problems than it solved." In general, the systems were thought to be somewhat useful but not fully solving the problem. Several types of operational problems were encountered: One system did not satisfactorily track moving aircraft. The lights of taxiing aircraft often blanked out another system. Problems occurred at airports where the camera could not be located to avoid looking directly into the sunrise or sunset. Problems with depth perception were encountered. Most airports reported their CCTV systems to be almost useless at night, though some airports were able to use their systems by having adequate lighting of the coverage area or by being able to see aircraft lights. Bad weather (rain, snow, fog) caused problems in some blind spot applications. However, in cases where the CCTV system was used to see areas distant from the tower (as opposed to obstructed areas) it often proved beneficial in bad weather, providing the visibility was not extremely poor.

The ten airports with CCTV systems have had a wide range of maintenance histories, from systems which required little maintenance to others which needed repair almost weekly. This, of course, resulted from the use of different equipment under different environments and with different degrees of skill in maintenance. (The installation and maintenance were often performed by a contractor engaged by the airport.)

Several airports have requested CCTV systems (indicating the existence of a blind spot or related problem) but have never installed the system. Table 2-14 shows the nine airports for

TABLE 2-14. CCTV REQUESTED BUT NOT INSTALLED: FY 1975-1981 BUDGET YEARS

AIRPORT	BUDGET YEAR	PURPOSE	COVERAGE AREA	STATUS OF REQUEST
Helena MT	FY 1975	To see behind buildings	A taxiway and a short portion of a runway	Withdrawn: Review of project downgraded its priority, and reconfiguration of airport lessened need
Richmond VA International	FY 1976	To see behind trees (which act as a sound barrier)	Approach to a runway and an adjacent taxiway	Withdrawn: Region withdrew request based upon assessment of its experience with CCTV
Albany NY Albany County	FY 1976	To see behind a build-ing	A ramp and taxiway	Withdrawn: Same as above
Washington DC Dulles International	FY 1976	To see surface areas not visible due to tower configuration	Areas not visible from north cab positions	Withdrawn: Same as above
Abilene TX Municipal	FY 1976	To see an area not visible due to distance and terrain	A portion of a taxi-way where aircraft just leave a runway	Withdrawn: Use of runway decreased
Dallas-Ft. Worth Regional	FY 1976	To see a distant area	A new runway	Withdrawn: Anticipated problem not as severe as expected
El Paso International	FY 1976	To see a distant area behind a terminal building	A part of a runway	Withdrawn: Airport reconfiguration substantially solved problem
Houston Intercont.	FY 1976	To see a distant area	A proposed runway and associated taxiway	Withdrawn: Proposed runway did not materialize
Denver Stapleton International	FY 1979 to FY 1981	To see runway area distant from tower	Approach end of a runway	Pending: Request nonvalidated and then appealed

which such requests were made for the FY 1975 to 1981 budget years. As shown in the table, eight of these requests were withdrawn, five because the need lessened or disappeared, and three due to the Eastern Region's reassessment of its requests based upon its experience with CCTV. The Eastern region feels that CCTV is not good when it is needed most, i.e., in bad weather.

One request is still pending, the request for the installation of CCTV to see the threshold of a runway which is over three miles from the tower at Denver Stapleton International Airport. NAFEC performed a feasibility study of the use of CCTV in this application (Reference 2.6). This study concluded that a CCTV system can be satisfactorily used as an aid to assist the Air Traffic Controller in monitoring traffic at the threshold area.

The Denver budget request was not validated by the ATC System Programs Division (AAT-100). This was based upon their experience that CCTV systems installed by the regions have not performed up to expectations. They cite two major problems: lack of depth perception and poor nighttime viewing. They have asked the Airways Facilities Service (AAF) to assist them in finding state-of-the-art equipment that can effectively meet the needs at Denver and are deferring further action until they receive AAF's recommendations. AAF has responded to this request by updating a 1968 FAA Handbook entitled "Closed Circuit Television for Airport Blindspot Surveillance -- Equipment Selection and Establishment Guidelines" (Reference 2.7). A draft of the updated Handbook is scheduled for early 1979, with the official version to be published later in that year. The Denver request is being resubmitted as part of the FY 1981 budget request, and is still pending.

Table 2-15 shows the actual costs for the two existing CCTV systems, Honolulu and Boston, and for one recently deactivated system (Longview, TX). The table also shows the estimated costs for the one system with budget request still pending, Denver. For the Boston system, in addition to the actual costs for the system paid by the airport to a contractor, the table includes estimates by the region as to how much the system would have cost had it

TABLE 2-15. CCTV SYSTEM COSTS (1978 DOLLARS)

AIRPORT	MAJOR COST COMPONENTS			TOTAL SYSTEM COST	
	QUANTITY	EQUIPMENT TYPE	UNIT COST IF KNOWN ($1000's)	COST BASIS	COST ($1000's)
Honolulu International	2	CCTV Camera	$ 1.9	Actual cost For contract	$16.4
	2	Environmental Enclosures	$ 0.9		
	2	Monitors	$ 0.7		
		Installation			
		12-months maintenance			
Boston Logan International	2	CCTV Cameras	$ 8.0	Actual cost For contract	$63.0
	2	Zoom Lenses	$ 3.0		
	1	Pan/Tilt Mount	$ 1.5		
	2	Environmental Enclosures	$ 0.6	Estimated cost if bought directly using off-the-shelf items	$45.0
	1	Transmitter	$ 0.8		
	1	Receiver	$ 1.7		
	2	Monitors	$ 1.2		
	1	Equipment Enclosure	$ 0.5	Estimated cost if bought directly through GSA	$32.0
	1	Microwave Link	$ 5.0		
		Installation			
		4-months Maintenance	(All costs estimated off the shelf)		
Denver Stapleton International	2	CCTV Cameras	$ 9.2	Estimated cost	$84.0
	1	Power Optics with Pan/Tilt; Lens; Envir. Enclosure	$32.0		
	1	Power Optics (No Pan/Tilt); Lens; Envir. Enclosure	$ 2.8		
	1	Microwave Transmission System	$13.7		
	1	Manual Switch	$ 4.8		
	1	Tower (including Installation)	$ 3.0		
			$ 4.1		
		Installation (Travel and Per Diem only)	(All costs estimated)		
Longview TX Gregg County Airport	1	CCTV Camera	$ 1.6	Actual cost	$ 4.2
	1	Monitor	$ 1.7		

been bought directly using off-the-shelf equipment prices, and also how much the system would have cost had the equipment been purchased through GSA.

2.5 VISUAL SURVEILLANCE AND THE TOWER CAB

In good cab visibility conditions, controllers (Ground Control and Local Control) currently use visual surveillance to locate and control aircraft. In bad cab visibility conditions, ground surveillance radar provides all of the surveillance needs for Local Control, but not for Ground Control. As pointed out in Section 2.1.3, if a system of surveillance could be devised which would provide Ground Control with all his surveillance needs, a good deal of his lost capacity (51%) would be restored. This is the motivation for the TAGS system described later in Section 3.2.

However, the reason that airport traffic control towers are built is to provide an adequate platform for controller visual surveillance. If a system can be built which provides both cab control positions with adequate surveillance without visually looking out of the cab (i.e., in bad cab visibility), cannot such a system be traded off against the cost of a tower?

This concept is quite revolutionary and has not been explored by the ASTC program to date. However, as revolutionary as it may seem, there are large potential benefits. The cost of a new level IV or V tower is high with approximately $15 million (1978 dollars) estimated for a new facility at New York--JFK. A system which would truly eliminate the need for such a tower and permit Ground and Local Control to take positions in the TRACON would not only have financial benefits but could improve controller coordination and loosen cab-related TRACON siting constraints. Although such a benefit is not included in the surveillance system benefits estimated subsequently in this study, it should be borne in mind when considering the possible development of such a surveillance system.

3. OPTIONS AND ALTERNATIVES

3.1 ADDED GROUND CONTROL POSITIONS

One potential solution to Ground Control capacity limitations during bad cab visibility conditions is to add a third ground controller. A third voice frequency could be set aside for this position and, when necessary, a controller assigned to staff the position. If feasible, this would be a relatively low cost solution since only when extreme weather conditions existed would an extra controller be required, possibly called in for a shift of overtime. However, there is evidence that this is not a practical solution to the problem.

Chicago O'Hare currently staffs two ground controllers on a regular basis. The division of responsibility is between arrivals and departures. Operations are fairly well balanced between arrivals and departures during the busy periods and this division results in a good workload split (i.e., approximately 50/50). The two ground controllers stand side by side since most of the ramp area and closed-spaced taxiways are to the south and this gives both controllers a good view of the south side and aids in inter-ground control coordination. However, it does this at the expense of Ground Control/North-side Local Control coordination

Despite the good workload split at Chicago, communication channel workload analysis (Reference 1.3) indicates that during bad cab visibility with an ASDE-2 in operation the difference between one and two ground controllers is only a 40 percent gain in capacity. This relatively low gain is most likely due to the traffic of one controller impacting on the other and creating the need for added position reports and conflict resolution. As pointed out in Reference 1.3, the only way to avoid this is to geographically divide controller responsibility. However, this would introduce the need for added Ground Control coordination and inter-Ground Control handoffs, both of which tend to increase work load as exemplified by current problems at Denver Stapleton (Reference 2.2) and Los Angeles (Reference 2.3).

As indicated in Reference 2.2, Denver Stapleton is having difficulty defining an effective division of Ground Control. Geometry-based divisions which efficiently divide workload tend to greatly increase the need for inter-controller coordination and handoffs due to the congested conditions in the close-in taxiways and ramp area. Similar conditions exist at Los Angeles where Ground Control is divided geographically into a north side ground controller and a south side ground controller. The airport itself, runways, taxiways and ramp areas, is divided into a north side and a south side with two taxiways joining the two sides. However, traffic into and out of the two sides of the airport is not divided equally with about 70 percent of the traffic being associated with the south side. Because of this, the addition of a north side controller to aid the south side controller only reduces his load by 30 percent. In addition, inter-controller handoffs on the two crossing taxiways must then be added to the controllers' workload. For this reason, Los Angeles rarely utilizes two ground controllers even in heavy volume, good visibility conditions despite the occasional saturation of the single (south-side-based) ground controller. In especially severe conditions, Los Angeles does add the second controller but, the south side controller continues to be pacing.

From existing experience, it is apparent that the utilization of a second ground controller is inefficient even with a perfect division of workload and that a good division of workload might be impossible at some airports. The same conditions which cause this inefficiency can only get worse when a third ground controller is added. In Figure 3-1 estimates of the impact of a third ground controller are shown for different workload divisions. In making the estimates it is assumed that the communication time spent by the i^{th} controller (T_i seconds per hour) is proportional to the operations under his control (n_i operations per hour) and to the operations under control of the other ground controller(s) (n_T-n_i, where n_T is the total operations per hour). Using the one and two controller estimates given in Reference 2.2 of 61 and 85 operations/hour respectively, the estimate for the communication

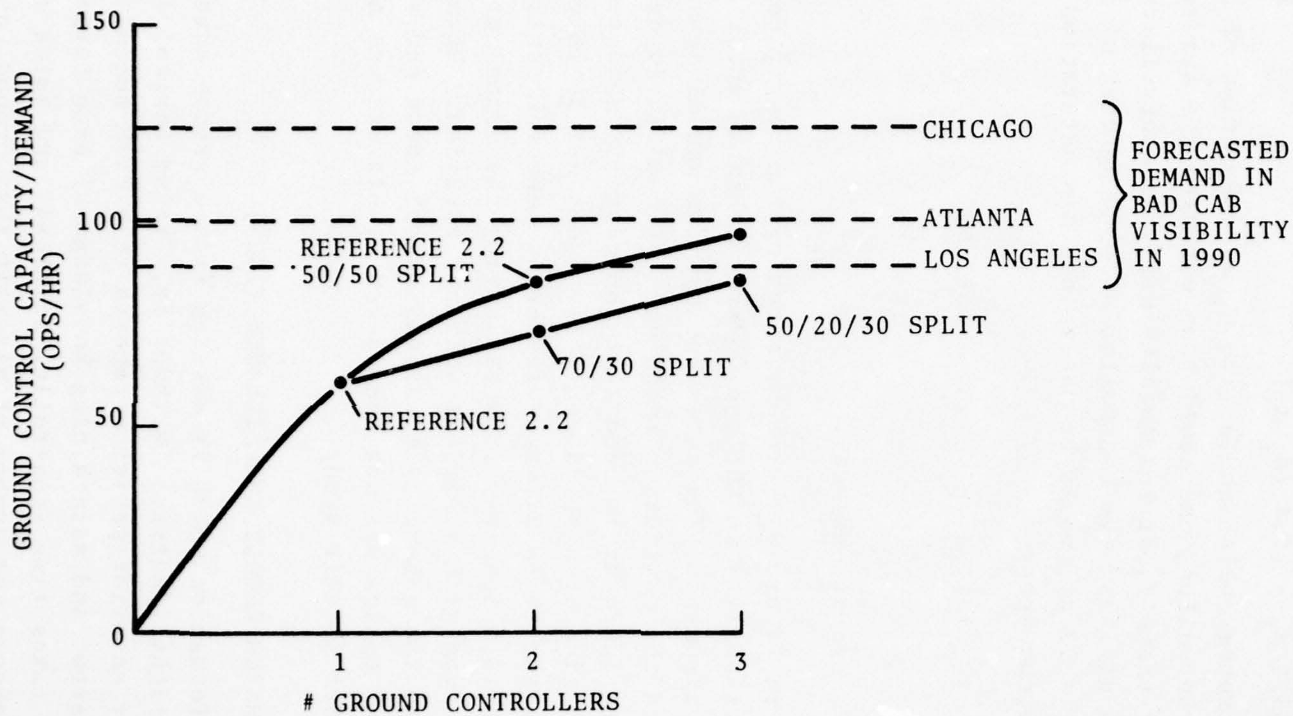


FIGURE 3-1. ESTIMATE OF IMPACT OF THIRD GROUND CONTROLLER

time of the i^{th} controller was computed to be:

$$T_i = 35.4\ n_i + 15.4\ (n_T - n_i) \qquad (4)$$

Given a split strategy which would give n_i as a function of n_T for the pacing controller, one could then estimate the saturation capacities. For example, at Los Angeles with two controllers and a 70/30 workload division the controller with 70 percent of the traffic (i.e. $n_i = .7\ n_T$) would be pacing and his saturation capacity would occur when

$$35.4 * .7n_T + 15.4\ (n_T - .7n_T) = .6*3600 \qquad (5)$$

or when

$$n_T = 73 \text{ operations/hour.} \qquad (6)$$

Also shown in Figure 3-1 are estimates of the hourly demand during bad cab visibility at Chicago O'Hare, Atlanta Hartsfield, and Los Angeles airports. The estimates use the annual demand from Reference 2.4 and the estimation technique followed in Reference 1.17. From this figure it is seen that the capacity gain resulting from the addition of a third controller does not satisfy the demand at any of the three airports (given an imperfect split at Los Angeles) and is a long way from satisfying the demand at Chicago O'Hare, even with a perfect workload division. Because of this, and due to the general limitations on cab space and voice frequencies, this option was not considered viable and was not considered further in this study.

3.2 TOWER AUTOMATED GROUND SURVEILLANCE (TAGS)

The key information which is missing from a ground surveillance radar is flight identity. Without it, Ground Control is required to rely on pilot position reports to aid in mentally tracking each target and maintaining knowledge of each target's identity. This takes time (controller workload) and voice channel capacity, and reduces the number of aircraft that Ground Control can service. The primary objective of TAGS is to augment the

ASDE-3 display with flight identity data blocks. A TAGS display mock-up is shown in Figure 3-2.

The TAGS system concept shown in Figure 3-2 has been termed a hybrid system. It combines the information provided by ASDE-3 as one subsystem with flight identity provided by a computer-based target location and identification subsystem. There are many technical alternatives for implementing the target location and identification subsystem. These alternatives are considered in detail in a TAGS technical alternatives analysis (Reference 1.16), the results of which are summarized in Section 5 of this report. The recommended alternative is one which uses the ATCRBS beacon which is currently installed onboard each aircraft (the candidate airports are Group I Terminal Control Areas) for airborne ATC application. A detailed description of the subsystem is presented in Reference 3.1. A summary description follows.

The recommended target location and identification subsystem uses beacon interrogation stations and beacon reply receiver stations located about the airport surface. An example installation is shown in Figure 3-3 for Chicago O'Hare. The interrogators are used in pairs in a special interrogation scheme aimed at interrogating only one target at a time thus preventing the garble of multiple returns. The receivers are used in triads to determine location by measuring the beacon reply time-of-arrival at each station and performing trilateration computations. The receiver also receives a beacon code which is correlated with flight plan information available from the ARTS computer to provide flight identity. The identity is then added to the radar display at the proper target location resulting in the hybrid display. As an added feature, the Ident. function of the ATCRBS beacon can be received along with the beacon code and translated into a ground controller cue on the radar display (e.g., to replace verbal taxi requests).

A second TAGS system concept considered in the TAGS technical alternatives analysis is the use of the ATCRBS-based target location and identification subsystem alone to provide a TAGS display

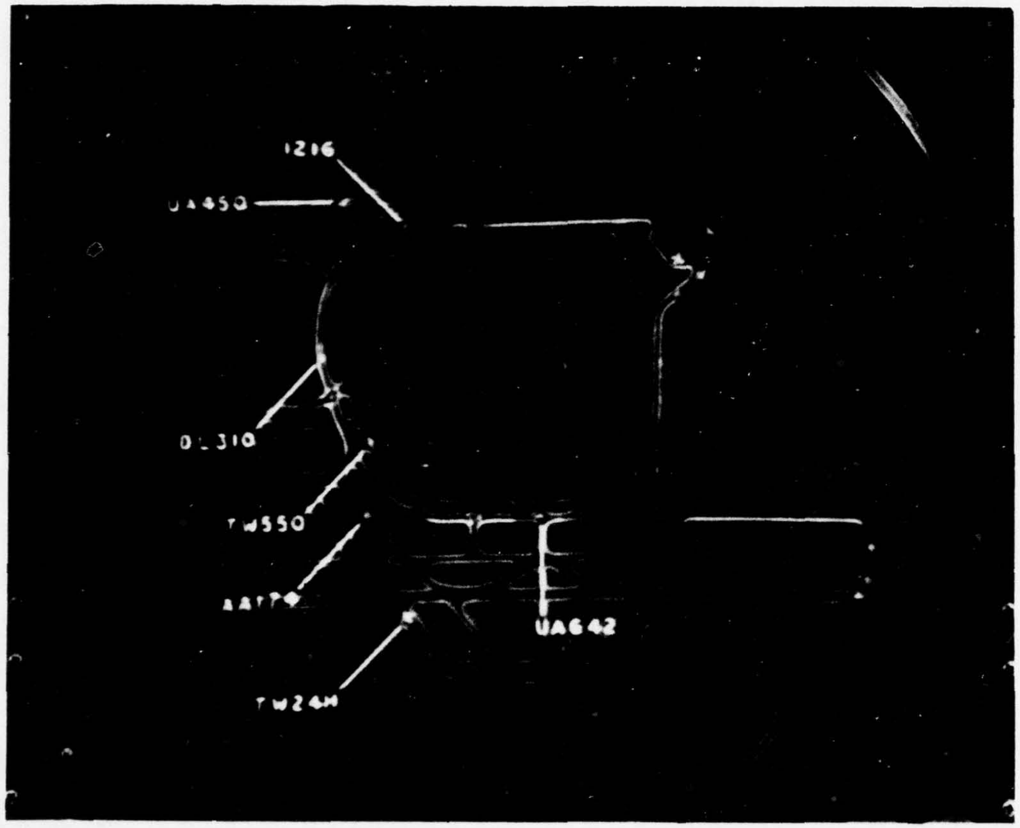


FIGURE 3-2. TAGS HYBRID DISPLAY MOCKUP

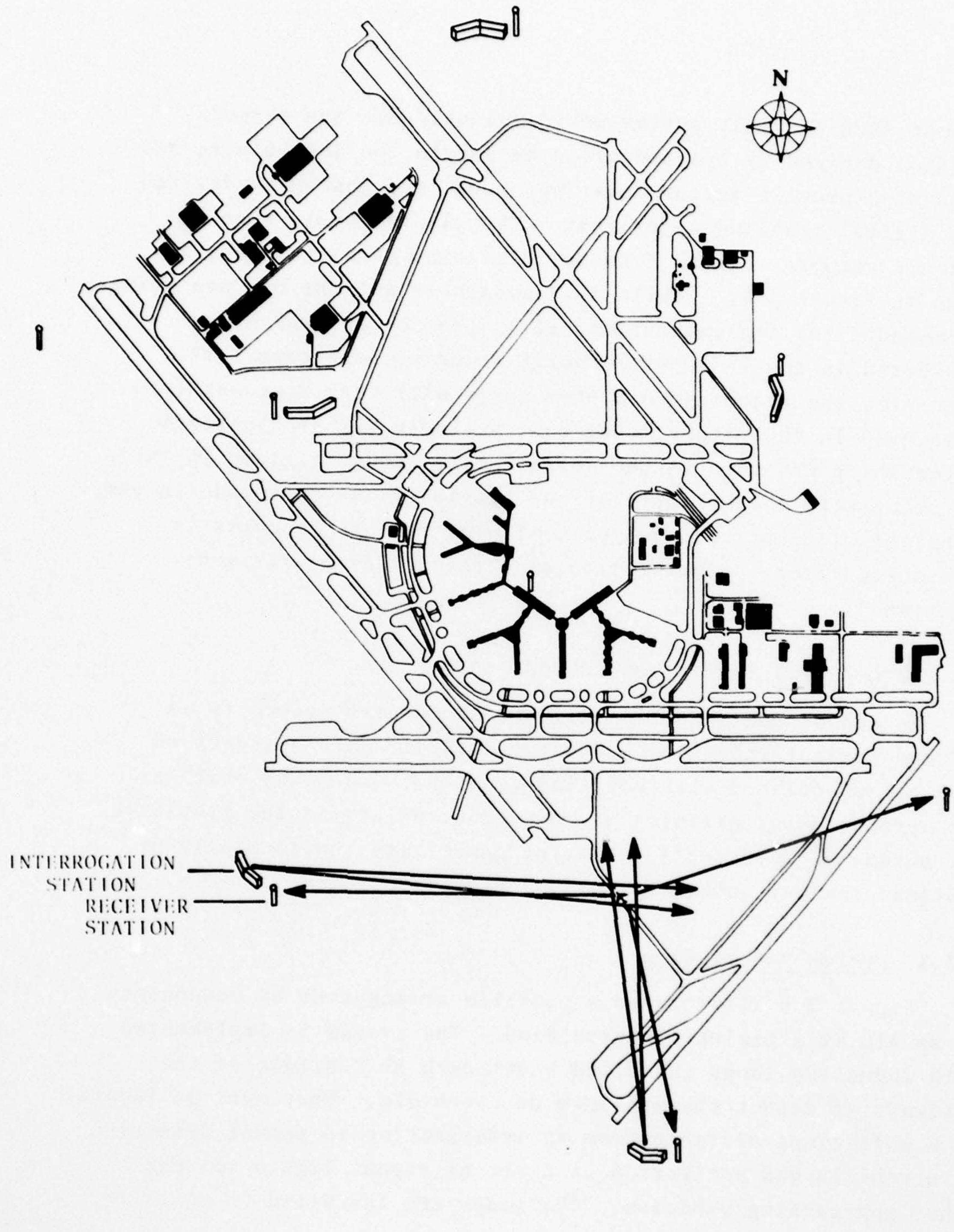


FIGURE 3-3. TARGET LOCATION AND IDENTIFICATION SUBSYSTEM INTERROGATOR/RECEIVER STATIONS (NOT TO SCALE) AT CHICAGO O'HARE

without ASDE-3. This system would not only use the target location derived by trilateration to locate the data block, but would also provide target location, speed and course as derived from digital tracking algorithms. The display would then be entirely computer driven (synthetic with no radar targets) as shown in Figure 3-4. While this system is not the one now being recommended for implementation, it is the concept which was considered in the TAGS cost/benefit study of Reference 1.17. Therefore, the recommended system costs will vary somewhat from those used in that study. The cost estimate for the synthetic system which was used in the cost/benefit study is given in Table 3-1 along with the estimate of the hybrid system cost made in the technical alternatives analysis. The difference in costs is considered later in the section on alternatives comparisons (Section 4).

3.3 AUTOMATIC INTERSECTION CONTROL (AIC)

As discussed in Section 2.1, ground control capacity is reduced during periods of bad cab visibility due to increased workload associated with position reports. One means that has been proposed for offloading ground controllers is the provision for automatic intersection control capability, particularly at critical taxiway intersections (high traffic volume).

3.3.1 System Description

Figure 3-5 illustrates a possible arrangement of components of an AIC at a taxiway intersection. The system is implemented with inductive loops installed underneath the surface of the taxiways to detect the presence of a vehicle. They must be located at a sufficient distance from an intersection to permit detection of a vehicle and activation of a set of signal lights to warn other approaching vehicles. The loops are installed in pairs to provide adequate reliability.

The first set of loop detectors informs the system of the presence of an aircraft on the taxiway approaching an intersection.

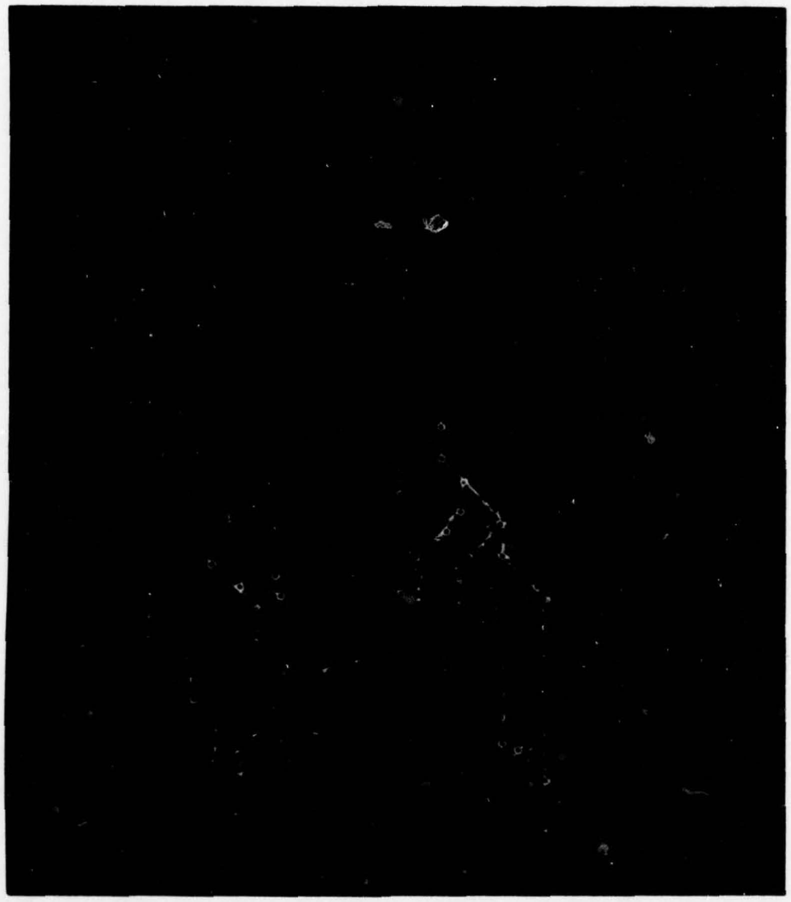


FIGURE 3-4. TAGS SYNTHETIC DISPLAY - SIMULATED

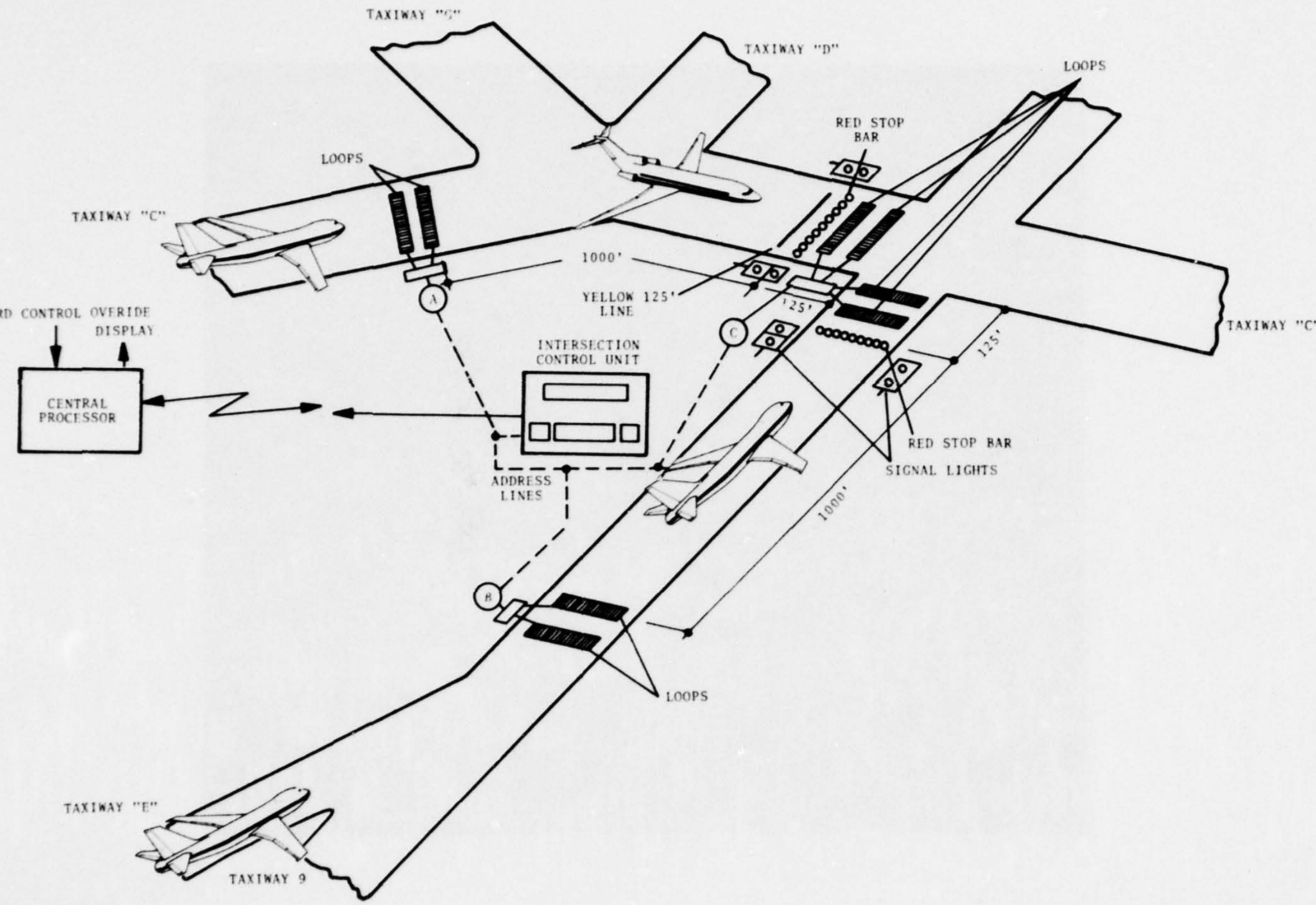


FIGURE 3-5. AUTOMATIC INTERSECTION CONTROL SYSTEM

TABLE 3-1. TAGS SYSTEM COST ESTIMATES

TYPES OF COST	SYSTEM COSTS ($ MILLIONS 1978) SYNTHETIC* OPTION		SYSTEM COSTS ($ MILLIONS 1978) HYBRID OPTION	
Development Costs				
Prototype/Engineering Model	4.6		5.2	
Government In-House Costs	3.5		3.5	
Subtotal	8.1		8.7	
Production Costs				
Chicago Unit	1.6	Ave. 1.6	1.6	Ave. 1.9
Los Angeles Unit	1.6		2.1	
Atlanta Unit	1.6		2.1	
Subtotal	4.8		5.8	
TOTAL PROGRAM COST	12.9		14.5	

*As specified in the Cost/Benefits Analysis (Reference 1.17), adjusted to 1978 Dollars at 5 percent/year.

This set would be located from 500 to 1000 feet from the stop bar and signal lights to allow sufficient time for a taxiing aircraft to brake to a stop without causing excessive discomfort to the passengers. The stop bar and signal lights would be positioned so that the aircraft would be stopped prior to encountering the clearance line (125 feet from the intersection). The signal lights located at the sides of the taxiway provide an additional 50 to 100 feet warning to the pilot versus over-the-nose viewing of the stop bar lights. The second set of loop detectors provides either an indication of an aircraft's crossing the stop bar due to failure to stop on signal, or verification that an aircraft has proceeded into the intersection on command.

Sensor signals from the loop detectors and command signals to the stop bars and lights are transmitted to/from a central computer via intersection control units located in the general vicinity of the controlled intersections. These units would be hard-wired to the AIC components installed at taxiway intersections, with two to four units required per airport depending on the number of intersections instrumented and the airport geometry.

A central computer installed in the airport control tower, contains the logic for implementing the intersection control strategy selected for the runway configuration in use. Data transmission between the central computer and the intersection control units would be via landlines.

The ground control positions in the tower would have a display and control panel interconnected with the central computer. This panel would enable the ground controller(s) to select the mode of operation and strategy for AIC's, and to monitor the status of aircraft in the vicinity of taxiway intersections.

A previously conducted case study of the application of AIC at three airports imposed the requirement for one-way traffic flows for each runway configuration, with some pavement additions needed for implementation. With this traffic pattern established, it was found that AIC installation at approximately 25 intersections at each airport provided coverage of all conflicts occurring

during yearly use of the taxiways. Approximately 80 percent of the yearly conflicts would be covered by AIC's installed at the ten most critical intersections at each airport.

Figure 3-6 shows the location of the ten most critical intersections at Logan International Airport (Boston). The additional paving required to establish a one-way traffic flow pattern is also shown on the figure.

3.3.2 Estimated Cost

Table 3-2 is a summary of the costs of AIC components, and estimates of total installed cost for an airport based on coverage of ten critical intersections at Logan International (Boston). Unit costs are based on estimates for similar components used in analogous applications. Cabling costs have been estimated using approximate lengths of cable runs obtained from a layout of Logan International Airport. The cost of additional paving required to establish one-way traffic flows is not included in the cost estimates.

3.3.3 Operational Limitations

Certain types of taxiway intersections pose operational difficulties which tend to compromise the efficiency of an automatic intersection control system.

When an arriving aircraft exits a runway, and approaches a taxiway intersection in close proximity to the runway, the system must give priority to the exiting aircraft. At an exit speed of 40 knots, approximately 500 feet are required to brake an aircraft to a stop without causing excessive discomfort to the passengers. Since the choice of runway exit is known only to the pilot, aircraft approaching taxiway intersections located within 500 feet of an active runway must be held until the aircraft on the runway has cleared the intersection or left the runway via another exit. If the arriving aircraft uses another exit, aircraft on the intersecting taxiway will have been unnecessarily delayed.

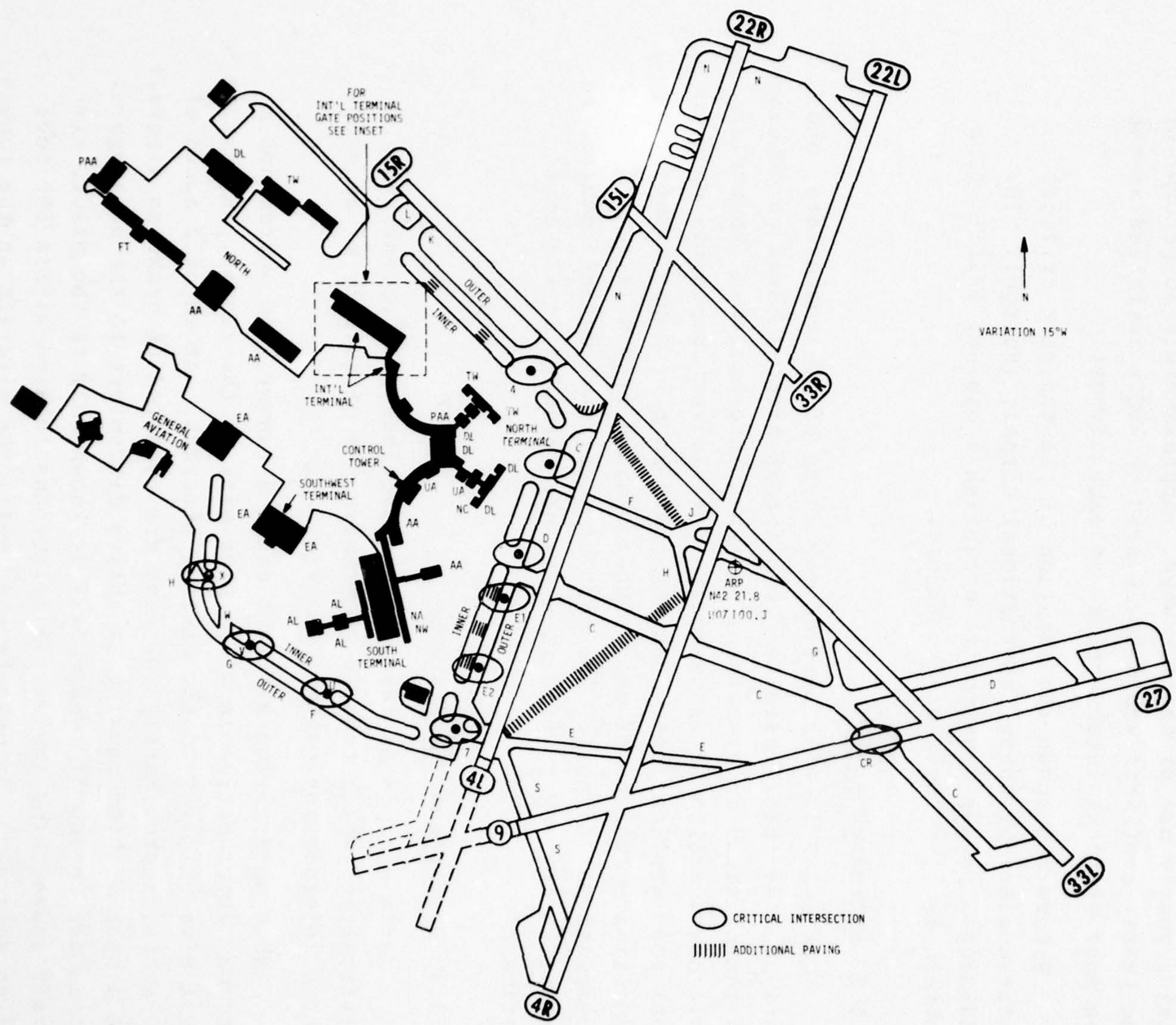


FIGURE 3-6. CRITICAL INTERSECTIONS AT LOGAN INTERNATIONAL

TABLE 3-2. AUTOMATIC INTERSECTION CONTROL COST ESTIMATE
(1978 DOLLARS)

ITEM	UNIT COST (INSTALLED)	NUMBER PER AIRPORT[(1)]	COST PER AIRPORT[(1)]
	($1000)		($1000)
Loop Detectors	4.0	100	400
Signal Lights	0.5	56	28
Stop Bar	10.0	28	280
Intersection Control Unit	65.0	4	260
Tower Control/Display	5.0	1	5
Central Processor	5.0	1	5
			Subtotal 978
Power Conditioning/Cabling			150
Data Communication Lines			60
			Total 1188

[(1)] Based on coverage of 10 critical intersections at Logan A/P.

Another type of intersection that can result in unnecessary delay due to AIC limitations is illustrated by intersection number 4 in Figure 3-4. An aircraft traveling inbound on taxiway N after exiting runways 4L, 4R or 33R might intend to proceed directly through intersection 4 to the North Terminal, or turn left onto the outer taxiway and proceed to the South Terminal. An aircraft travelling on the inner taxiway may be delayed unnecessarily due to the AIC's lack of knowledge of intent of the aircraft on taxiway N, and the close spacing (250 feet) between the outer and inner taxiways.

Close spacing between taxiways could also be the cause of other unnecessary delays using an AIC system. With distances on the order of 250 feet, as is the case between inner and outer taxiways at Logan International (Figure 3-6), most commercial aircraft holding on the connecting stubs would have their tails projecting into the departed taxiway. This could unnecessarily delay other aircraft intending to proceed along the departed taxiway. A ground controller, with knowledge of the total surface traffic location and pilots' intent, can control traffic to optimize the flow and minimize delays. An AIC cannot.

3.4 STANDARD TAXIWAY ROUTING (STR)

Current procedures call for Ground Control to route each aircraft at the time of taxi clearance. This is done in spite of the fact that at busy, high air carrier activity airports most of the aircraft take standard routes based upon their destination (e.g., take-off runway), their origin (e.g., the airlines gate area), and the runway configuration in use. Routing messages and associated workload represent a substantial percentage of the controllers overall workload. (See Section 2.1.3). The objective of an STR system is to reduce this workload, freeing up the controller to deal better with other work areas (e.g., surveillance during bad cab visibility).

The STR system concept uses the DABS (Discrete Address Beacon System) data link to transmit computer generated standard taxiway

routes to aircraft at the time of flight plan information transmission. The system could probably use the same cockpit-pilot interface used to transmit flight clearance data. The system would generate the routes in terms of the existing taxiway names and sign system. Sets of maps or charts giving all possible routes versus all possible route determination parameters would not be required in this system (as opposed to some standard Taxiway routing concepts). A computer driven display and data entry device would be required by the Flight Data position to enter the route determination parameters which are required (e.g., runway configuration in use). In addition, Ground Control would require a display indicating the transmitted route for each aircraft.

The STR system has been briefly described in References 1.1, 1.3, and 1.8. Benefits estimation is documented in Reference 1.3. The system has not evolved beyond the concept stage. No preliminary design work has been done. There is no feasibility analysis or cost estimate.

3.5 AUTOMATIC GROUND TRAFFIC CONTROL

In the late 1960's expanding terminal facilities at New York JFK airport created a potential line-of-sight problem for the tower cab. As an alternative to the construction of a new tower, the Port of New York Authority (PONYA) contracted for the preliminary design of an Automatic Ground Control System (AGCS). The system was not to address Local Control since line-of-sight to the runways was not a potential problem. The system (termed STRACS-Surface Traffic Control System) was based upon a network of inductive loop vehicle detectors and in-pavement taxiway lights installed at taxiway intersections to provide surveillance and control commands, respectively. Control algorithms were to be exercised by a central digital computer and were to include routing as well as intersection control. The inductive loops were built and tested, and with some modification, were found to be acceptable for aircraft detection. However, neither the AGCS nor the new tower was implemented since the line-of-sight problem did not

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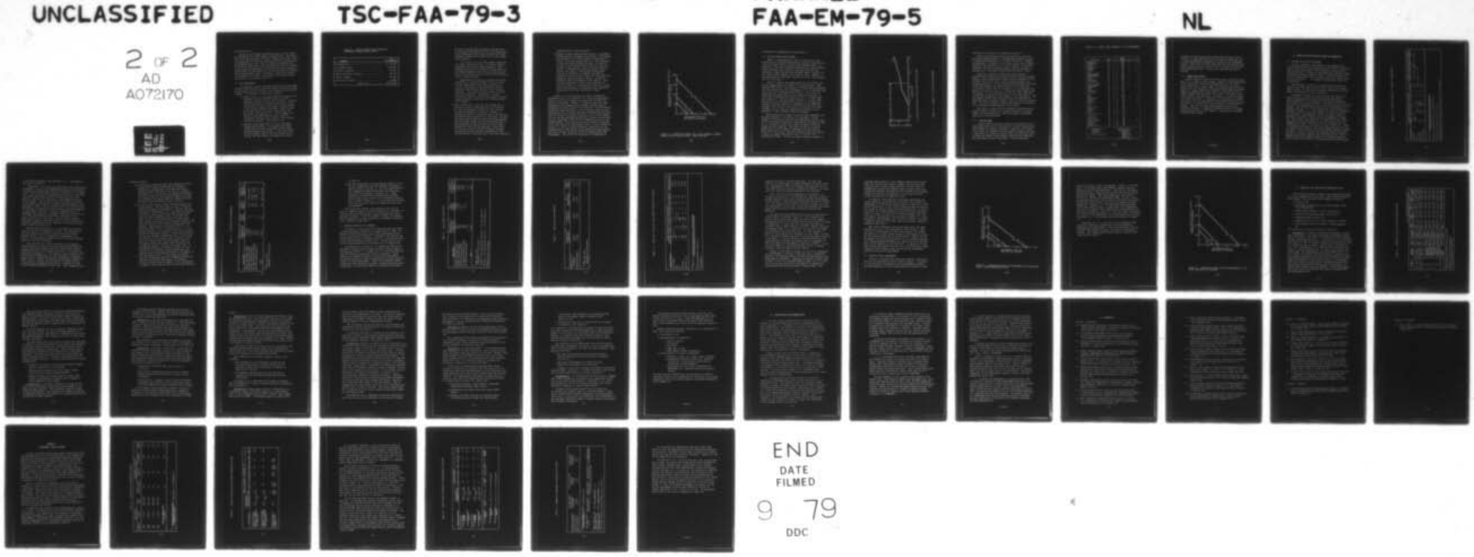

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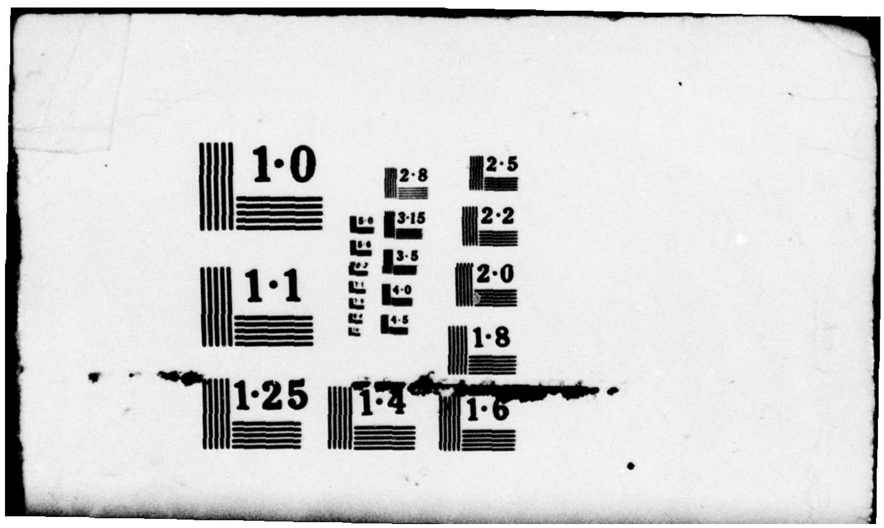
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fully materialize.

During the ASTC Concept Formulation study, the AGCS concept was re-examined as it might apply at Chicago O'Hare. The motivation was as an alternative to TAGS for solving the bad cab visibility problem and as a means for reducing controller staffing needs. The equipment layout for a system at O'Hare was hypothesized. Since the loop based AGCS is not cooperative and aircraft identity is not known, the destination of every aircraft must be manually entered into the system before the aircraft may enter the taxiways and be automatically routed. Therefore, a controller interface was included in the layout. An estimate of the system initial capital cost (I) is given in Table 3-3.

3.6 TAGS ENHANCEMENTS

If a decision is made to develop the TAGS system, many added features become possible by using the target position as provided by the target location and identification subsystem and the TAGS computer. Some possible features are as follows:

1) Conflict Alert - it is possible that algorithms could be developed to enable the TAGS computer to predict potential conflicts and alert the controller. Conflicts could include those at taxiway intersections, at the intersection of runways and taxiways, and on taxiways as one aircraft overtakes the other. Benefits which would accrue could be as much as $93,000 per year per airport (See Section 2.3). This is roughly five percent of the annual benefits due to capacity improvements during bad cab visibility ($1.8 million per year per airport. (see Section 2.1.2).

2) Automatic Intersection Control (AIC) and Standard Taxiway Routing (STR) - It is possible that these alternatives, previously discussed, could be implemented through the use of TAGS. In the case of STR, the TAGS computer would be used for processing the routing, the TAGS display and keyboard entry would

TABLE 3-3. INITIAL CAPITAL COST ESTIMATE FOR AN AUTOMATIC GROUND CONTROL SYSTEM

ELEMENT	COST, 1978 DOLLARS
Loop Detectors..................................	$ 695,000
In-Pavement Lights..............................	1,510,000
AC Power & Cabling..............................	870,000
Signal Interfaces & Cabling.....................	925,000
Central Computer................................	870,000
Controller Interface............................	70,000
Total Cost.................	$4,940,000

be used as the controller interface, and TAGS would be interfaced with DABS data link for STR transmission. A STR transmission would likely coincide with flight clearance transmission and could use the same cockpit-pilot interface.

In the case of AIC, the TAGS computer would have the target location and could use the TAGS computer to generate the aircraft stop/go commands. These commands would then be transmitted via DABS data link. The commands would be quite basic and could probably utilize the ATARS (Air Traffic Advisory and Resolution Service) cockpit display.

Implementation of these two concepts using TAGS (assuming it is available) would be far less costly than the stand alone system costs, especially for the AIC. Motivation for the enhancements would be increased Ground Control capacity in all visibility conditions. This would help reduce delay in bad cab visibility conditions. In addition, it might eliminate the need to staff with two ground controllers in good visibility conditions, thus realizing productivity benefits.

3) Local Control Cues - This study has assumed that in good cab visibility conditions the local controller has all the information required to clear arrivals to land and departures to take-off. However, if metering and spacing is installed, and if two nautical mile inter-arrival separations are permitted, the local controller might become the capacity-limiting element. With the target surface location provided by TAGS, it may be possible to provide time-to-clear-the-runway estimates for arrivals and departures. These could then be used along with time-to-threshold estimates for arrivals on final approach, generated from ARTS derived position, to provide cues to the local controller

regarding these two key clearances.

4) Automatic Airport Surface Traffic Control - Independent studies have been performed (see Section 3.5) to examine the feasibility of a fully automatic Ground Control System. Given that productivity (i.e., the elimination of controller positions while providing the same ATC service) is the chief motivation, the costs for such a system, as investigated, clearly exceed the benefits. However, once TAGS is installed and surface target location is available to a computer, and DABS is installed with its data link, the costs associated with automation should be greatly reduced. In addition, automation could be extended to Local Control. Using the same assumptions as those used to generate the curves in Figure 2-11, benefit/cost curves for a system which would eliminate all ground and local controllers (10 man shifts per site) are given in Figure 3-7.

To date, very little work has been done to examine the requirement for, or the feasibility of, these TAGS enhancements. Priority on available resources has been given to ASDE-3 and the basic TAGS system. However, it should be noted that these enhancements would probably require highly accurate position information on surface targets in digital form. The ASTC Concept Formulation Study (Reference 1.8) estimated positional accuracy requirements for all control functions. Movement detection which would be required for conflict resolution, AIC, and full automation was the most demanding function and resulted in a positional accuracy requirement of 16 feet (one standard deviation at four samples/second). This high accuracy would probably be required of any Local Control Cue algorithms as well. As was discussed in Section 3.2, there are several technical alternatives for the implementation of TAGS and not all alternatives provide adequate positional accuracy (in digital form) to implement these TAGS enhancements. This factor was considered in recommending an

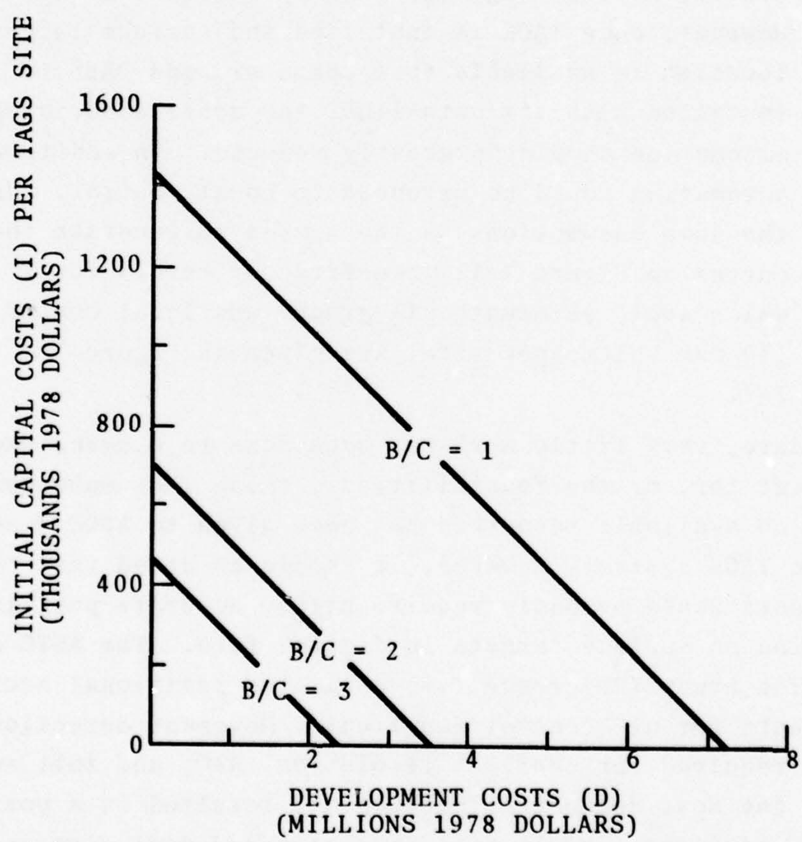


FIGURE 3-7. BENEFIT/COST CURVES FOR A FULLY AUTOMATIC AIRPORT SURFACE TRAFFIC CONTROL SYSTEM - BASED UPON TAGS

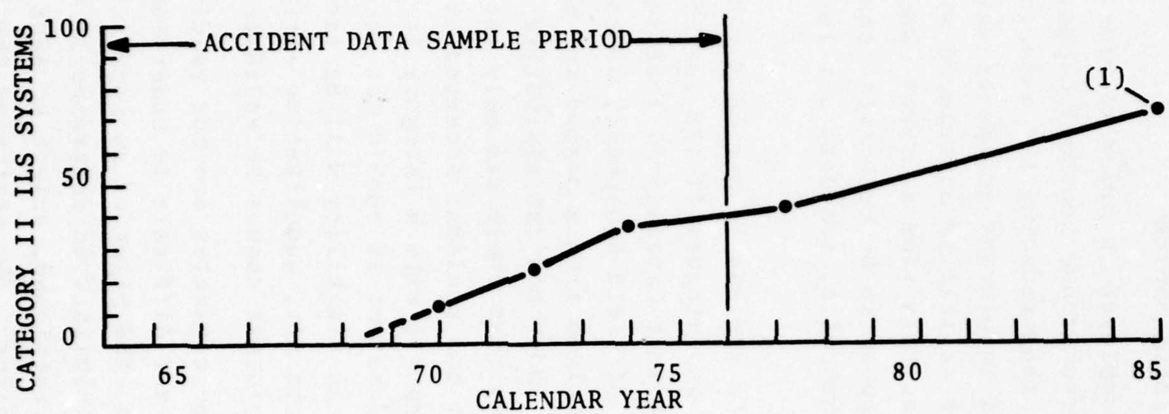
alternative for implementation (see Section 5).

3.7 LOW COST SURVEILLANCE SYSTEMS

ASDE-3 is being deployed in order to restore lost Local Control (and to a degree Ground Control) capacity during bad cab visibility conditions thus reducing the associated delay. In addition, it will tend to prevent accidents which could otherwise result from poor pilot visibility associated with the same conditions. Based upon data from accident reports (Section 2.3), the safety benefits appear to be relatively small. However, in this application of that data, the data set is not truly representative of the future.

Figure 3-8 depicts the sample period for the accident data and the recent growth in category II ILS installations. When combined with the fact that Category II traffic build-up generally lags the installation of field equipment, it can be seen that most of the data set is obtained from a period in which very few operations took place under bad cab visibility conditions. It should not be suprising that there was only one accident under such conditions. That one accident occurred at Chicago O'Hare, the busiest of the airports with a Category II ILS capability. Therefore, from this data set it should not be construed that accidents due to bad cab visibility will be rare in the future although, without a data set, quantitative estimates of the potential for such accidents cannot be validated.

While quantitative estimates are not readily obtainable, the accident potential is not difficult to understand. During Category II conditions, the pilot of an approaching aircraft does not have sufficient visibility to determine if the runway is clear (e.g., of another aircraft) and, unless an ASDE is installed, neither can the controller. The status of the last aircraft authorized to use the runway is reported to the controller by voice radio, but in poor visibility conditions that pilot may be in error, or another pilot may be lost, or in error, and occupying the runway. No positive runway clearance assurance is



(1) Based upon National Aviation System Plan 1976-1985

FIGURE 3-8. CATEGORY II ILS INSTALLATION HISTORY

provided the controller or the approaching aircraft.

ASDE-3 will provide such positive assurance at the busy instrument approach airports. The deployment planned for ASDE-3 as specified by Reference 1.14 is given in Table 3-4. However, the deployment of Category II ILS systems exceeds that of ASDE-3. Therefore, some airports will be left to operate in visibility conditions for which no positive runway clearance assurance is provided (e.g., San Antonio International and Windsor Locks).

There are a variety of systems and system concepts in existence which could provide positive runway clearance assurance. However, since no quantitative benefit has been estimated to substantiate the need for such a system and give guidance as to allowable system cost, little work has been done along these lines by the ASTC program. One approach would be to consider the surveillance system a part of a category II ILS installation and specify its cost to be low (e.g., ten percent) when compared with the Category II ILS system costs so as to not unduly upset the cost/benefit rationale for the Category II ILS installation. Then the cheapest system within that constraint, and providing the necessary runway clearance assurance, would be selected for deployment. The costs to upgrade a runway from Category I to Category II are estimated at about $550,000 (1978 dollars).

Two types of systems which are intended to provide positive runway clearance assurance are currently installed at foreign airports for operational use. Brief descriptions (along with their costs) are given below.

3.7.1 Low Cost ASDE

To give controllers the cues necessary to provide for the high traffic levels at the busy airports, a high resolution radar such as ASDE-3 is required. However, if used at a low traffic level airport to provide a more gross runway clearance assurance, a radar with less resolution would suffice, and resolution could be traded off against system antenna complexity and system cost. Two such radars are now in existence: a system originally

TABLE 3-4. ASDE-3 AND CATEGORY II ILS DEPLOYMENTS

AIRPORT AND STATE	STATE ABBREV.	HUB	RANK	FY 1977 INSTRUMENT APPROACHES	ASDE-3(1)	CAT II(2)
Los Angeles Intl	CA	L	1	49626	Y	Y
Chicago O'Hare Intl	IL	L	2	42681	Y	Y
Pittsburgh Greater Intl	PA	L	3	37630	Y	Y
Atlanta Intl	GA	L	4	32057	Y	Y
Miami Intl	FL	L	5	29731	Y	
Seattle Tacoma Intl	WA	L	6	27874	Y	Y
San Francisco	CA	L	7	23295	Y	Y
Boston Logan	MA	L	8	22161	Y	Y
Portland Intl	OR	M	9	21625	Y	Y
La Guardia	NY	L	10	20189	Y	Y
Santa Ana	CA	L	11	17129		
Houston Intercontinental	TX	L	12	16532	Y	Y
Rochester Monroe County	NY	M	13	16456		
Cleveland Hopkins Intl	OH	L	14	16212	Y	
Indianapolis Weir Cook	IN	M	15	16000	Y	Y
Buffalo	NY	M	16	15799	Y	Y
St. Louis	MO	L	17	15116	Y	
Philadelphia Intl	PA	L	18	14759	Y	Y
San Diego Lindberg	CA	M	19	14467	Y	
Detroit Metro Wayne Co	MI	L	20	14360	Y	Y
Minneapolis St. Paul Intl	MN	L	21	14181	Y	Y
Dallas Ft. Worth Regional	TX	L	22	14161	Y	Y
John F. Kennedy Intl	NY	L	23	14127	Y	Y
Washington National	DC	L	24	13776	Y	Y
San Antonio	TX	M	25	13565		Y✓
Columbus	OH	M	26	12559		
Pontiac	MI	L	27	12132		
San Jose Municipal	CA	S	28	12001		
Charlotte Douglas	NC	M	29	11696		
Seattle Boeing	WA	L	30	11255		
Oakland	CA	L	31	11153		Y✓
Ontario	CA	S	32	10908		
Memphis	TN	M	33	10345	Y	Y
New Orleans Moisant	LA	L	34	10273	Y	Y
Milwaukee Mitchell	WI	M	35	10020	Y	Y
Long Beach	CA	L	36	9548		
Windsor Locks	CT	M	37	9505		Y✓
Cincinnati Greater	KY	M	38	9375	Y	Y
Kansas City	MO	L	39	8820	Y	Y
Burbank	CA	L	40	8711		
Dallas Love Field	TX	L	41	8690		
Newark	NJ	L	42	8410	Y	Y
Nashville Metropolitan	TN	M	43	8081		
Grand Rapids	MI	S	44	7987		
Albany County	NY	M	45	7570		
Allentown	PA	S	46	7513		
Honolulu	HI	L	47	7397	Y	
Tulsa	OK	M	48	7229		
White Plains Westchester	NY	N	49	7189		
Houston Hobby	TX	L	50	7173		
Fresno Air Terminal	CA	S	51	7025		
Fort Lauderdale	FL	L	52	6996		
Dayton	OH	M	53	6906		Y✓
Baltimore Washington Intl	MD	M	54	6702	Y	Y
Salt Lake City Intl	UT	M	55	6584		Y✓
Denver Stapleton Intl	CO	L	56	6552	Y	
Tampa	FL	L	57	6451	Y	Y
Wilkes Barre	PA	S	58	6218		
Birmingham	AL	M	59	6197		
Louisville Standiford	KY	M	60	6017		

(1) Plus Washington Dulles Intl. VA
Chicago Midway, IL.
Las Vegas, NV.
Phoenix, AZ
Newburgh-Stewart, NY

✓ Has Category II ILS but not ASDE-3

(2) From Airman's Information Manual March 23, 1978
Plus: Camp Springs, MD ✓
Columbia, SC ✓
Fairbanks, AK ✓
Jacksonville, FL ✓
Oklahoma City, OK ✓
Orlando, FL ✓
Sacramento, CA ✓
Washington-Dulles, VA

designed for harbor surveillance, manufactured by Decca, which is installed at London/Heathrow Airport for test and evaluation; and a system manufactured by Dannebrog and located at the Copenhagen Airport. Both units are X-band, have small vertical aperture light weight antennas, and are very basic units to realize low installation and operating costs. System costs range from $150,000 to $200,000.

3.7.2 Runway Surveillance

Another trade-off to make in order to reduce system cost (over ASDE-3) is to reduce system coverage. CORAIL, a system manufactured by LCT (Laboratoire Central de Telecommunications), is such a system which covers a single runway (or possibly a dual lane pair). Several units are installed at Paris/Orly and Paris/Roissy airports. CORAIL is a fixed antenna, pulse Doppler, X-band radar which is simply pointed along the runway to be covered. The radar provides range, velocity, and angle data, for targets on or near the runway, on a bright TV display. In addition, it can provide this information for aircraft on final approach within eight nautical miles of the airport. Airborne targets are presented on a second bright TV display. Thus, not only does CORAIL provide positive runway clearance assurance, it eliminates ASR/ARTS surveillance coverage gaps which may exist on final approach. System cost is estimated at $345,000 (per runway).

4. BENEFITS ESTIMATION AND ALTERNATIVES COMPARISON

4.1 THE BAD CAB VISIBILITY PROBLEM

The most significant ASTC problem is the reduced Ground Control capacity which occurs during bad cab visibility conditions. This not only causes ground delays but places pressure on the ground controllers to operate at and beyond their saturation capacity which may possibly impact on safety. This problem can occur today at Chicago O'Hare and will begin to occur on a regular basis at Atlanta Hartsfield and Los Angeles International airports by the mid-1980's.

The alternative solutions to this problem as described in Section 3 are TAGS, ASDE-3 and AIC, ASDE-3 and STR, and combinations of these. In addition, an Automatic Ground Control System (AGCS) could potentially solve the problem.

To estimate the benefits associated with each alternative, data and analysis results from the early ASTC requirements analysis (Reference 1.3) and from the ASTC Concept Formulation Study (Reference 1.8) were combined. As described in Section 2.1.3, the controller communication (service) time was measured at several airports. The service time was divided into five categories as defined in Section 2.1.3. Each category was examined to determine the factor by which it would be reduced if a given alternative were installed. The generation of these improvement factors is explained in Appendix A and the factors are summarized in Table A-4. These factors were applied to the appropriate service time categories for each alternative to arrive at estimates for the reduced service times. The results are given in Table 4-1. Given the reduced service time, it was assumed that added aircraft could be handled by the controllers and new saturation capacity estimates were made. Finally, to see how the improved capacity would aid the bad cab visibility problem, the forecasted bad cab visibility demand at the three candidate airports was estimated using the latest forecast data, and the estimation method used and described

TABLE 4-1. BAD CAB VISIBILITY CAPACITY IMPROVEMENTS

System Alternative	Average Communication Time/Aircraft (Seconds): Surveillance	Conflict	No Conflict	Gate	Other	Total	Capacity[1] OPS/Hour	1990 Demand in Bad Cab Visibility - OPS/Hour[3]: Chicago O'Hare	Atlanta Hartsfield	Los Angeles
With ASDE-3	20.4	9.0	11.1	2.3	8.1	50.9	85	123	101	90
TAGS	4.7 (.23)[4]	9.0	11.1	2.3	8.1	35.2	123			
AIC & ASDE-3	20.4	4.5 (.50)[2]	11.1 (2)	2.3	8.1	46.4	93	COMPARE		
STR & ASDE-3	20.4	9.0	4.0 (.36)	2.3	8.1	43.8	99			
AIC, STR & ASDE-3	20.4	4.5	4.0	2.3	8.1	39.3	110			

[1] $\text{Capacity} = \dfrac{\text{(2 Controllers * 0.6 Saturation Factor *3600 Seconds/Hour)}}{\text{Total Average Communication Time/Aircraft (Seconds)}}$

[2] Reduction Factor Estimate from Reference 1.3 Findings (See Appendix A)

[3] Estimated as in TAGS Cost/Benefit Study from Reference 2.4

[4] Reduction Factor Estimate from combination of data from Reference 1.3 and 1.8 (See Appendix A)

in the TAGS cost/benefit study (Reference 1.17). This demand is also given in Table 4-1.

From Table 4-1 it is seen that TAGS offers by far the greatest improvement. This was to be expected based upon the distribution of controller workload among the various categories (i.e., Figure 2-10). In fact, of the five alternatives in Table 4-1, only TAGS will resolve the bad cab visibility limitations at all three airports. The next best alternative is the combination of AIC, STR, and ASDE-3. This alternative falls far short of providing for the demand at Chicago and it requires the development of two operational systems. The AIC equipment alone will cost more than half the cost of TAGS and there are serious reservations regarding its operational feasibility. The STR is dependent on fleet equippage with a new piece of equipment (DABS data link) which is still under development and, therefore, realization of its' benefits may be far in the future. The only other alternative which might completely solve the bad cab visibility problem is an Automatic Ground Control System. However, its' costs far exceed those of TAGS (see Section 3.5).

Based on these observations, it is concluded that the TAGS system is the most cost-effective solution. The development of this one system will completely solve the bad cab visibility problem, and will serve as a platform for enhancements (see Section 3.6) which might be required to deal with future problems during all visibility conditions.

Given the selection of TAGS as the best of the suggested system alternatives, the merits of developing and deploying such a system have been examined by means of a cost/benefit analysis comparing TAGS with a "do nothing" alternative. This analysis is presented in Reference 1.17. The analysis results indicate a very cost-beneficial program which is quite insensitive to parameter changes such as increased system costs and decreased estimates for traffic growth. However, the referenced cost/benefit analysis included several assumptions which must be re-examined in light of new information presented in this study. These assumptions are

treated as follows:

(1) The analysis assumed that TAGS would completely restore Ground Control capacity during bad cab visibility conditions. Re-examination of the data collected at Chicago indicates that this is not the case. However, from Table 4-1 it is seen that the average hourly demand forecast for 1990 will be satisfied by TAGS at all sites and, therefore, the reduced capacity estimate would have no impact on the cost/benefit analysis results.

(2) The new traffic forecast differs from the forecast used in the analysis. This was shown in Figure 2-7 and will impact on the present value benefits. New York JFK will not require a TAGS system at all. The forecasted benefits estimated for JFK will not be realized but the system costs will not be expended either. To estimate the impact of the revised traffic forecast on the present value benefits estimated in the cost/benefit analysis, the benefits accruing to each TAGS unit deployed have been examined. These benefits are shown in Table 4-2, as taken from Table 3-3 and 3-4 of Reference 1.17. As can be seen from Table 4-2, the benefit from JFK was a small fraction of the overall benefit. Chicago and Atlanta are the two major benefits contributors and, as can be seen from Figure 2-7, their latest traffic forecasts closely match the forecast used in the cost/benefit analysis. Los Angeles traffic does depart from that used in the cost/benefit analysis, leveling off at about 1985. In considering the delay cost curves in Figure 2-8, this leveling off is estimated to approximately halve the benefits which were estimated to accrue to Los Angeles in the cost/benefit study. If the Chicago and Atlanta benefits are realized, half the Los Angeles benefits are realized, and the New York benefits are dropped, a revised net benefit can be computed. This is presented in Table 4-2 and results in only a nine percent reduction

TABLE 4-2. TAGS PRESENT VALUE BENEFITS

TAGS UNITS	Reference 1.17 Present Value Benefits(1)	Percent Total Benefits	Traffic Reduction Factor	Revised Present Value Benefits
Chicago Development Model	9,182			
Chicago Production Model	10,823	70	1.00	20,005
Atlanta Production Model	4,774	17	1.00	4,774
Los Angeles Production Model	2,517	9	0.50	1,259
New York Production Model	1,345	4	0.00	0
TOTAL	28,641	100	0.91	26,038

(1) Base Year 1976

Thousands of 1975 Dollars

in benefits.

(3) The TAGS system used in the cost/benefit analysis is not the one recommended by the TAGS technical alternatives analysis (refer to Section 5). The costs associated with the recommended technical alternative are higher than those used in the analysis (see Table 3-1). These increased costs have been translated into increased present value costs as used in the cost/benefit analysis. This is shown in Table 4-3. It is seen that the increased unit costs are nearly offset by dropping New York from the deployment.

The revised costs and the revised benefits from item (2) above are compared with the results of Reference 1.17 in Table 4-4. As can be seen, the TAGS system is quite cost beneficial with a good deal of margin. As was the original estimate, this program would be expected to be quite insensitive to parameter variations (e.g., increased system costs).

4.2 POTENTIAL PRODUCTIVITY INCREASES

In Section 2.2, ten airports are identified which are likely to staff two ground controllers on a regular basis by 1990. The potential benefit which would result from eliminating the need for the second ground controller is estimated at $63,000 per year (1978 dollars) and cost constraint curves for a system which could do this were presented (in Figure 2-11). In this section, each of the system alternatives are considered for this application.

In performing this analysis, it is assumed that TAGS will be deployed to Chicago O'Hare, Atlanta Hartsfield, and Los Angeles International airports. From Table A-4, it is seen that TAGS will have some benefits in good cab visibility conditions. These benefits are estimated in Table 4-5 and reflect approximately a ten percent increase in capacity suggesting a one ground controller capacity of 98 operations/hour. Using the relationship between average busy hour operations and annual itinerant operations given in Reference 2.5, the hourly capacity is translated into annual

TABLE 4-3. TAGS PRESENT VALUE COSTS

TAGS UNITS	Reference 1.17 Present Value Costs[1]	Cost Increase Factor	Revised Present Value Costs
Chicago Development Model	5,994	1.06[2]	6,354
Chicago Production Model	983	1.23[3]	1,209
Atlanta Production Model	983	1.23	1,209
Los Angeles Production Model	983	1.23	1,209
New York Production Model	983	0[4]	0
TOTAL	9,926		9,981

(1) Base Year 1976
Thousands of 1975 Dollars

(2) Factor = \$8.7 Million/\$8.1 Million = 1.06 (See Table 3.1)

(3) Factor = \$5.8 Million/\$4.8 Million = 1.23 (See Table 3.1)

(4) New York unit eliminated

TABLE 4-4. REVISED TAGS COST/BENEFITS

	Present Value[1] Benefits	Present Value Costs	Net Present Value	Benefit/ Cost
Reference 1.17 Estimates	28,641	9,926	18,715	2.9
Revised Estimates	26,038	9,981	16,057	2.6

(1) Base Year 1976
Thousands of 1975 Dollars.

TABLE 4-5. GOOD CAB VISIBILITY ONE GROUND CONTROLLER CAPACITY

System Alternative	Average Communication Time/Aircraft (Seconds): Surveillance	Conflict	No Conflict	Gate	Other	Total	Capacity[1] OPS/Hour	Capacity, Annual[2] Itinerant Operations
Current System	7.1 (.61)[3]	4.3	7.5	3.1	2.7	24.7	88	464,000
TAGS	4.3	4.3	7.5 (.36)[3]	3.1	2.7	21.9	98	517,000
STR	7.1	4.3	2.7	3.1	2.7	19.9	109	575,000
TAGS & STR	4.3	4.3 (.50)[3]	2.7	3.1	2.7	17.1	126	665,000
TAGS, STR, & AIC	4.3	2.2	2.7	3.1	2.7	15.0	144	759,000

(1) $\text{Capacity} = \dfrac{(1\ \text{Controller} * 0.6\ \text{Saturation Factor} * 3600\ \text{Seconds/Hour})}{\text{Total Average Communication Time/Aircraft (Seconds)}}$

(2) Based upon Appendix C : Reference 2.5

(3) See Appendix

capacity in terms of itinerant operations. For TAGS, this capacity is 517,000 annual itinerant operations as shown in Table 4-5. Examination of Table 2-2 indicates that TAGS alone at the three TAGS sites will not have a productivity benefit. All three sites will require two ground controllers even with TAGS.

Next, the AIC and AGCS alternatives are considered. As discussed in Section 3.5, even the AGCS will require an operator (ground controller) and so will eliminate only the second ground control position. Given the costs associated with the two systems (i.e., $1.2 million for AIC and $4.9 million for AGCS), it can be seen from Figure 2-11 that even if they could eliminate the second ground control position, neither alternative would be cost beneficial.

The capacity of one ground controller with an STR system but without TAGS is estimated in Table 4-5. This system has the greatest impact on the most significant service time category during good visibility, No Conflict Control associated with routing. Its improvement is larger than that associated with TAGS and translates into an annual capacity of 575,000 itinerant operations. In examining Table 2-2 it is seen that this satisfies the demand at virtually all seven non-TAGS sites. The only exception is Dallas-Ft. Worth and here the difference is very slight. In addition, STR would eliminate the need for the second ground controller at Los Angeles. To see if STR would eliminate the need for the second position at Chicago and Atlanta given the deployment of TAGS, the capacity of the combined systems was estimated. As can be seen in Table 4-5, even with both TAGS and STR, two Ground Controllers would be required at both airports.

However, as described in Section 3.6, AIC can be implemented as an enhancement to TAGS once a DABS data link is operational. Therefore, the improved capacity with STR and TAGS with AIC as an enhancement was estimated. Comparing the capacity estimate shown in Table 4-5 with the forecasted demand in Table 2-2, it is seen that the resulting capacity will be adequate to eliminate the second ground control position even at Chicago O'Hare. The

resulting system would be a semi-automatic Ground Control system where most aircraft would receive standard route via data link along with their initial flight clearance, conflicts would be automatically resolved and commands issued via data link at most taxiway intersections, and TAGS would be available for the ground controller to monitor the operation, clear aircraft into the system, and take care of exceptional cases.

To summarize, when DABS data link becomes operational and flight clearances are automatically relayed to the aircraft, the development of an STR system could eliminate the need for a second ground controller at all the airports regularly using two controllers except for Chicago O'Hare and Atlanta Hartsfield. To be cost beneficial, the system would have to satisfy the cost constraint curves of Figure 2-11, modified to spread development costs over eight units. The modified curves are shown in Figure 4-1. Given the nature of STR equipment, this might be achievable. Therefore, as DABS and DABS data link evolve, the STR alternative should be examined in more detail.

When TAGS and DABS data link become operational, the implementation of AIC as a TAGS enhancement becomes feasible. TAGS with AIC as an enhancement and STR, taken together, do increase the capacity of a single ground controller sufficiently to eliminate the second position even at Chicago O'Hare. However, the AIC development costs would be spread over only two airports and might be so airport-geometry-dependent that a great deal of new development would be required at the second site. In addition, it would have to share the beneifts with the cost of two STR systems. Unless substantial safety benefits were accrued, the AIC enhancements would not likely warrant development.

4.3 POTENTIAL SAFETY ENHANCEMENT

Section 2.3 indicated that significant potential safety benefits exist at the high air carrier activity airports. In general, it is not possible to hypothesize system improvements without a detailed examination of each accident which has occurred at these

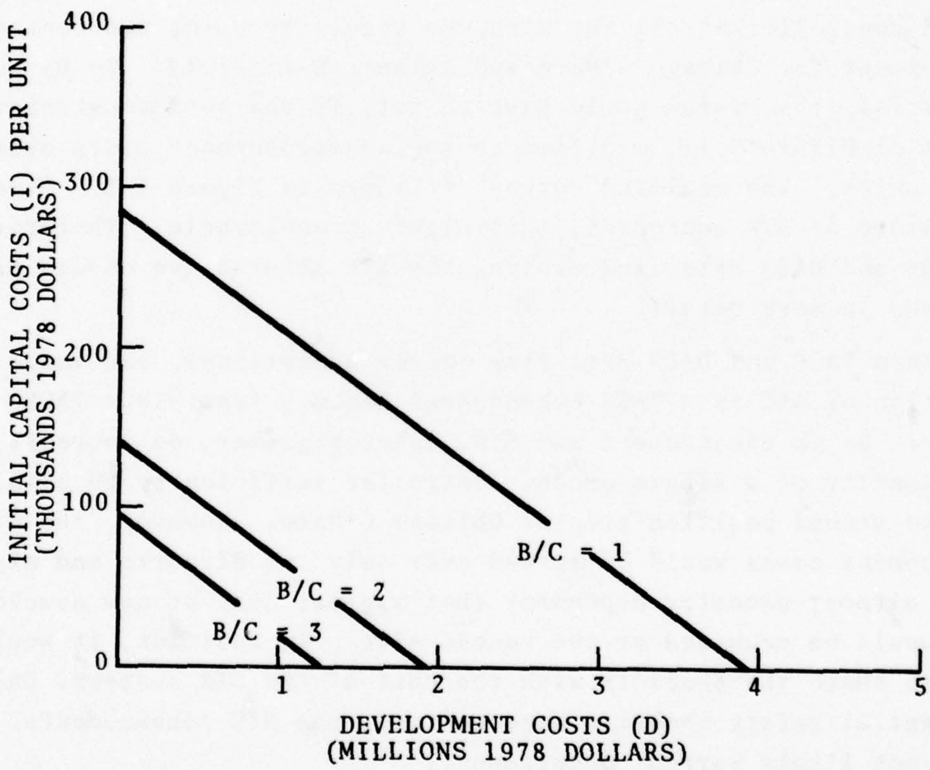


FIGURE 4-1. BENEFIT/COST CURVES FOR DEVELOPMENT OF STR FOR EIGHT SITES TO ACCRUE PRODUCTIVITY GAIN

airports, and such a study is recommended. However, at the TAGS sites, it is possible that safety benefits could be realized through the use of TAGS enhancements. Specifically, the enhancements which would be applicable are Conflict Alert and Automatic Intersection Control. These enhancements were described in Section 3.6. Whether such enhancements might, in fact, resolve the problems which led to the accidents at the TAGS sites requires further study and should be a part of the recommended accident examination. However, if it is assumed that such enhancements could prevent such accidents, an upper bound on the enhancement costs can be estimated. This bound would be the $93,000 per year per TAGS site quoted in Section 2.3. With this bound, the benefit/cost curves for the enhancements can be generated as was described in Section 2.1.2. The resulting curves are presented in Figure 4-2.

From Figure 4-2, it is seen that if the enhancements were successful, significant program costs could be expended for development and implementation. Since the enhancements would be primarily TAGS software additions, they might be economically feasible. This finding should further motivate a detailed ASTC safety/accident analysis.

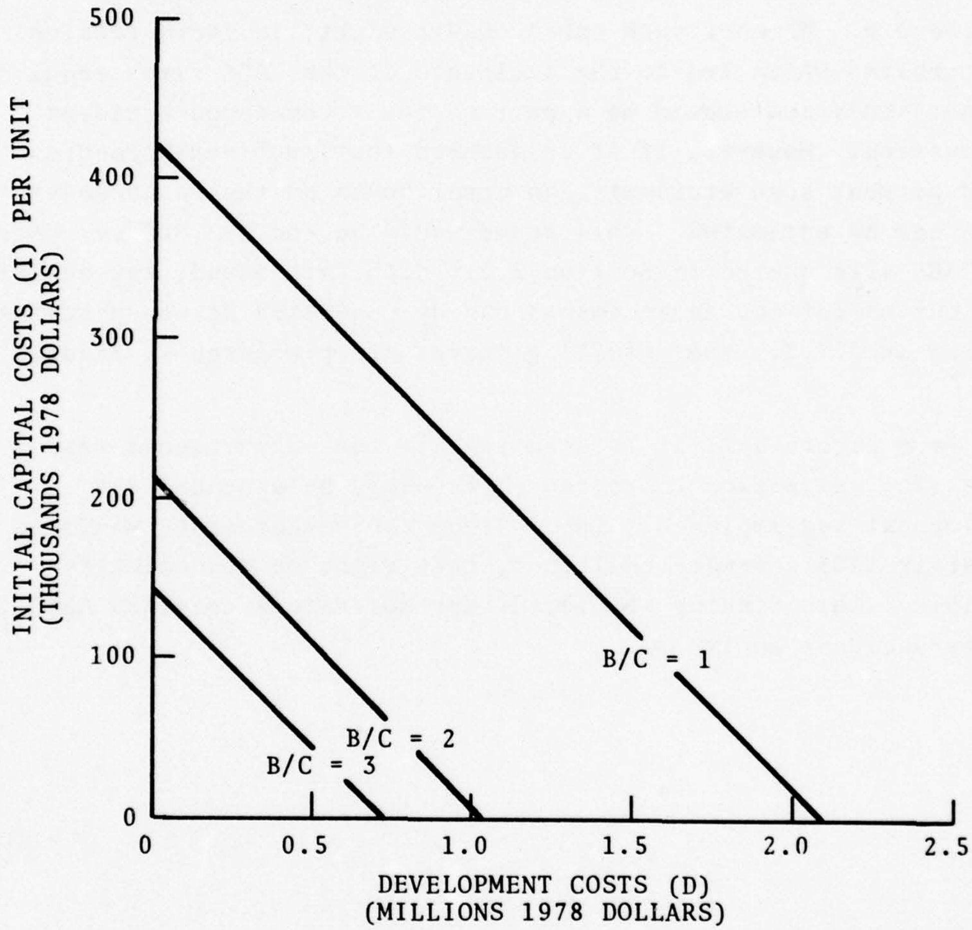


FIGURE 4-2. BENEFIT/COST CURVES FOR TAGS ENHANCEMENTS IF ALL SAFETY BENEFITS CAN BE ACCRUED

5. SUMMARY OF THE TAGS SYSTEM ALTERNATIVES STUDY

A TAGS System Alternatives Study has been completed (Reference 5.1) and is summarized in this section. Nine system alternatives were examined. The alternatives were compared in terms of:

- o Technical risk
- o Operational acceptability at the three potential TAGS sites (ORD/ATL/LAX)
- o System growth potential in terms of automation
- o Necessary pre-engineering model contract costs
- o Engineering model contract cost
- o Production unit cost for a system installed at O'Hare
- o Total Program cost which includes a 3-unit production buy.

The results of the study are presented in Table 5-1.

Alternative 1 is denoted as the Multi-Interrogator Trilateration System (MITS). The system interrogates the ATCRBS transponders of aircraft on the surface of the airport and in the immediate airspace surrounding the airport. To ensure that only one aircraft will reply at a time, the system's phased array interrogation sites are operated in pairs to create a 150-by-150 feet interrogation cell. The interrogation cell is electronically steered over the airport's aircraft movement area. To cover a large airport like O'Hare (ORD), five interrogation sites distributed over the airport surface are required. Aircraft position is estimated using a trilateration technique that uses the time differences of a transponder reply measured at three receiver sites. The transponder reply also contains aircraft identity information which enables the system to provide both aircraft location and identity. At O'Hare, eight receiver sites are required. To save site preparation costs, five of the receiver sites would be colocated with the interrogation sites.

TABLE 5-1. RESULTS OF THE TAGS SYSTEM ALTERNATIVES STUDY

ALTERNATIVE #		ALTERNATIVE DESCRIPTION	TECHNICAL RISK	OPERATIONAL ACCEPTANCE	SYSTEM GROWTH POTENTIAL	ESTIMATED CONTRACT COSTS[1] (MILLIONS) ENGINEERING MODEL DEVELOPMENT	PRODUCTION UNIT AT ORD	OTHER PRODUCTION UNITS	TOTAL[2] PROGRAM
	1	MITS	LOW	REJECTED	GOOD	$5.2M	$1.6M	$2.1M	$11.0M*
	2	MITS + LOOP	LOW	REJECTED	GOOD	6.6M	1.6M	2.8M	13.9M*
	3	MITS & ASDE	LOW	ACCEPTABLE	GOOD	5.1M	1.6M	2.0M	10.7M
HYBRID	4	MITS + ASDE	LOW	MOST ACCEPTABLE	GOOD	5.2M	1.6M	2.1M	11.0M
HYBRID	5	CENTRAL STATIC/ TRILATERATION	MODERATE	LIKELY ACCEPTABLE	DOUBTFUL	4.6M	1.4M	1.8M	9.5M
HYBRID	6	CENTRAL ROTATING/ TRILATERATION	MODERATE	LIKELY ACCEPTABLE	DOUBTFUL	3.9M	1.1M	1.6M	8.2M
HYBRID	7	CENTRAL STATIC/ RHO-THETA	MODERATE	REJECTION LIKELY	DOUBTFUL	3.7M	0.9M	0.9M	6.3M
HYBRID	8	CENTRAL ROTATING/ RHO-THETA	MODERATE	REJECTION LIKELY	DOUBTFUL	3.1M	0.6M	0.7M	5.1M
	9	DIGITIZED ASDE-3	UNKNOWN	REJECTION LIKELY	VERY LIMITED	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN

*POTENTIAL COST BENEFIT OF RELOCATING ASDE-3 UNITS NOT INCLUDED

(1) 1978 Dollars - excludes Government in-house costs.

(2) Includes a 3-production unit buy (ORD/ATL/LAX)

This alternative provides a clutter-free display presentation with synthetic targets and target identities (see Figure 3-4) which are unaffected by weather and, being a highly accurate all digital system, it provides a solid base for future system growth. The TAGS display would replace the ASDE radar display in the tower cab, and the ASDE unit would be made available for installation at another airport.

The basic components of the surveillance subsystem have been built and field tested. The tests are nearing completion. To date, the subsystem has been found to be compatible with the existing ATCRBS environment, and it appears to satisfy the TAGS system accuracy requirement.

The ASTC Program office has formally discussed the operational acceptance of this system alternative with control tower personnel at the three potential TAGS sites. One group found the system operationally acceptable and desirable. Another group liked the clean display presentation but was doubtful of its operational acceptance. The controllers expressed serious doubts about the lack of an ASDE backup to an all digital system which they felt would be subject to failures. The third group rejected the system outright due to:

- o Failure of the system to display nontransponder-equipped vehicles, particularly on the runways
- o Vehicle extent uncertainties of the display targets, particularly for runway clearance purposes.
- o Reduced coverage on the ramps relative to ASDE, which itself is considered by the control tower personnel as barely adequate for this purpose.

Alternative 2 is the same as Alternative 1 except for the addition of a subsystem of loops buried in the pavement at the runway entrances and exits. This subsystem is used for runway clearance determination. Each loop sets up a magnetic field that is measurably affected by the presence of a vehicle within five or ten feet of the loop's location.

The runway clearance subsystem improved the controllers' acceptance of the system. However, the subsystem increases the overall cost of the system substantially without eliminating some of the major operational objections.

Alternative 3 is the same as Alternative 1 except that the ASDE-3 system is retained for Local Control use. The TAGS display is used by Ground Control and the two displays are shared as required. This dual system meets the basic TAGS requirement of providing Ground Control with a surveillance display with tagged targets, and overcomes the objections that Local Control expressed with regard to alternatives 1 and 2 concerning compromised runway clearance information.

This alternative is operationally acceptable and involves low technical risk. However, it does not take full advantage of having two airport surveillance systems present in the tower cab.

Alternative 4 is the same as Alternative 3 except that the outputs of the two surveillance systems (i.e., MITS and ASDE-3) are combined into a single hybrid display presentation. The ASDE-3 channel provides the target images and airport map while the beacon-based channel provides target identities and leaders. The advantages of this hybrid approach over the dual approach described in Alternative 3 are:

- Ground Control would have ASDE ramp coverage on his display
- Local Control would have target ID and an all weather display, and would be able to share in future system enhancements
- In the event of a failure of one of the two surveillance subsystems, each controller could use the other system to provide backup surveillance information on his display.

In the airport surveys the hybrid system was clearly preferred over the all digital system alternatives. Among the alternatives, this one offers the highest level of operational acceptance plus low technical risk, and a solid base for system

growth.

Alternative 5 is one of several compromise alternatives aimed at reducing system cost. This alternative achieves a cost savings by centralizing the multiple interrogation sites on the airport surface to a single complex of phased array antennas mounted on the roof of the control tower. The system still uses receiver sites on the airfield for trilateration position determination once a transponder is interrogated. However, since interrogation would result from a "searchlight" beam revolving about the control tower instead of from the intersection of two narrow interrogation beams, garbled replies from more than one transponder will occur. Analysis of degarbling techniques indicates that garble rates might be able to be reduced to acceptable levels.

A preliminary analysis was made of the size and weight of the centralized interrogator antenna complex and its mounting on a control tower roof. The results indicate that mounting the antenna on the roof should pose no insurmountable problems.

This alternative has increased technical risk due to the following:

- o The performance of the interrogator antenna has not been field tested above a height of 30 feet and this alternative would require the antenna to function at heights up to 200 feet.
- o The degarble techniques upon which the operational acceptance of this alternative depends have not been field tested.

From Table 5-1 it is seen that this increase in technical risk is accompanied by a modest 14 percent savings in Program cost over Alternative 4.

Alternative 6 further reduces the cost of Alternative 5 by reducing the central interrogator complex to a single antenna which is then backmounted onto the ASDE-3 antenna. Both antennas would rotate at 60 RPM. A preliminary analysis was made of the

size and weight of the interrogator antenna required and the feasibility of backmounting it to ASDE-3. The analysis indicates that the antenna would be relatively small and light weight in comparison to the ASDE-3 antenna, and that the concept of back-mounting appears to hold no insurmountable problems.

This alternative retains the technical risk associated with Alternative 5, but has the potential of a 25 percent reduction in Program cost over Alternative 4.

It should be noted that in coupling the two antennas to the same mast, a failure in the antenna rotating mechanism would put both surveillance subsystems down, thereby compromising the operational redundancy inherent in Alternatives 4 and 5.

Alternative 7 attempts to reduce the cost of Alternative 5 in another way. The receiver sites on the airport surface are reduced to a single central receiver that is colocated with the central interrogator complex on the roof of the control tower. Aircraft position can no longer be determined by trilateration but must be determined by relatively inaccurate Rho-Theta measurements. The Rho-Theta position determination technique measures the range and azimuth from the interrogator-receiver to the target transponder. Target azimuth is measured by the aimed boresight of the interrogation beam. Target range is determined by measuring the roundtrip time from the interrogator antenna to target transponder and then back to the colocated receiver antenna. Of the system's inherent inaccuracies, the largest contribution is from bias errors associated with transponder retransmission delays. Tolerances permitted by the FAA specification governing ATCRBS transponders can result in 250-foot errors between the identity leaders and their associated radar targets on the TAGS display. Some GA transponders have been found to have bias errors that would cause display errors as large as 700 feet. Bias errors change slowly and, in contrast to jitter errors, cannot be effectively reduced by filtering the input.

The technical risk is comparable to that for alternatives 5 and 6, but the size of the displayed errors between the targets

and their associated identity leaders is apt to cause confusion, and is likely to cause controllers to reject this alternative. This alternative is a significant system compromise with respect to alternative 4, but has the potential of reducing the Program cost for TAGS by 45 percent.

Alternative 8 combines the cost cutting approaches of Alternatives 6 and 7 in that it utilizes the backmounted antenna concept for interrogation and the Rho-Theta concept for position determination.

This alternative could reduce the Program cost of Alternative 4 by 50 percent; however, it retains all of the features of Alternatives 6 and 7 which represent an increased technical risk, and the likelihood of controller rejection.

Alternative 9 is a digitized ASDE-3. It is potentially the least expensive of the nine alternatives, since the entire beacon-based surveillance subsystem would not be required. However, since digitized ASDE-3 has not progressed beyond a very early design stage, neither system cost nor technical risk could be evaluated during this study. It is possible, however, to examine the operational acceptability of a digitized ASDE-3.

In contrast to the preceding alternatives where target location and identity are provided to the TAGS processor by the surveillance subsystem, digitized ASDE-3 has the surveillance subsystem providing the processor with raw radar video and no target identity. To be operationally acceptable, the TAGS processor, using the radar video and information from interfaces with other air traffic control systems (e.g., ARTS), must:

1) Automatically acquire targets against a background containing considerable radar clutter,
2) Automatically tag targets with their actual flight numbers,
3) Maintain the target identities of acquired targets at intersections and in ramp areas where targets

can come into close proximity to one another and the order of the targets cannot be assumed by the processor, and

4) Automatically drop track of targets that are no longer of interest to the controller.

It is important to the operational acceptance of digitized ASDE-3 that these functions be provided automatically without requiring guidance or corrections to be routinely input by the controllers. However, it is expected that these functions cannot be fully automated using digitized ASDE-3 and that some routine inputs would be required of controllers.

The possibility of interfacing TAGS with other ATC systems currently under development, like TIPS, in order to eliminate the need to enter data manually into TAGS, has been considered. These potential interfaces

- o May reduce the workload associated with the manual entry of TAGS data but are not expected to eliminate the need for it
- o Would make TAGS dependent on systems for which operational acceptance is not yet assured.

In summary, a great deal of design work remains to be done on digitized ASDE-3, and there is a distinct possibility that the end result would be operationally rejected by controllers.

Recommendation: The primary technical factors used to compare TAGS system alternatives are technical risk, operational acceptability, and system growth potential. From Table 5-1 it is seen that alternatives 3 and 4 are the most promising, with 5 and 6 marginally acceptable, in terms of these factors.

Estimated total program contract costs for these four alternatives vary within a range of 2.8 million dollars. Since the net present value of TAGS is estimated at 16 million dollars (Table 4-4), or 18.6 million in 1978 dollars, this differential is not considered significant enough to justify selection of a marginally acceptable alternative.

The evaluation of mission need (Section 2) and the cost/benefits analysis (Section 4) calls for deployment of three TAGS systems over the next 15 years. Since TAGS deployment will be small, with no measurable benefits anticipated from additional units, lower production unit costs are not an important consideration.

Based on these observations, alternative 4 is recommended for TAGS. This alternative features

1) Low technical risk,

2) High operational acceptability:

- o Positive identity
- o All weather
- o Fail safe
- o ASDE ramp coverage
- o ASDE runway clearance information,

3) Growth potential in terms of automation:

- o Controller alarms (e.g., double runway occupancy)
- o Recommended controller actions (e.g., departure release cues if metering and spacing reduces longitudinal spacing minimums)
- o Providing pilots with control information via DABS/ATARS (e.g., automated intersection control/routing).

The study team has concluded that this alternative's technical superiority should not be compromised for the possible cost savings achievable with one of the more marginally acceptable alternatives such as number six.

6. CONCLUSIONS AND RECOMMENDATIONS

1. The most serious problem which can be quantitatively estimated is reduced Ground Control capacity during bad cab visibility conditions (e.g., Category II), even with a ground surveillance radar present. This problem can not only cause ground delays but can place pressure on the ground controllers to operate at and above their saturation capacity which may possibly impact on safety. This problem can occur today at Chicago O'Hare and will begin to occur at Atlanta Hartsfield and Los Angeles International by the mid-1980's. The only alternatives which fully resolve this problem at all three sites are TAGS (Tower Automated Ground Surveillance) and possibly an AGCS (Automatic Ground Control System). However, the cost estimate for an AGCS far exceeds that of a TAGS, leaving TAGS as the most cost-effective alternative.

A formal present value cost/benefit analysis, comparing a TAGS development program with the alternative of "doing nothing," indicates that a TAGS development program would be quite cost beneficial, and that the results are quite insensitive to parameter variations such as increased system costs. The proposed program is estimated to have a benefit/cost ratio of 2.6 and a net present value benefit of 16 million in 1975 dollars (18.6 million in 1978 dollars). In view of these findings, it is recommended that a TAGS development program aimed at satisfying the needs of the three candidate airports be undertaken.

2. A second problem associated with bad cab visibility conditions is developing which cannot be quantified due to an inadequate data base. This problem is the lack of positive runway clearance assurance at airports which will not get ASDE-3 but which will operate during bad cab visibility conditions (e.g., Category II). Under these conditions, neither the cab controllers nor the pilot of an approaching aircraft (such as a Boeing 747) can <u>see</u> if the runway is clear of another aircraft or vehicle. Since Category II ILS systems have only recently been installed, experience with this situation is limited. However, the consequences of this problem could be quite serious.

If a positive runway clearance assurance system were to be considered a necessary part of a Category II ILS, a ten percent cost expansion might not seriously reduce the net benefits associated with the Category II ILS installation and, therefore, might be a reasonable cost constraint for the added system. Using an estimated cost of $550,000 for a Category II ILS system, yields an added system cost constraint of $55,000. Candidate systems providing runway clearance assurance do exist and are operating in Europe; however, they do not satisfy the hypothesized cost constraint.

In view of the potential seriousness of this problem, it is recommended that the benefits associated with Category II operation be re-examined, and that a rational cost constraint on a positive runway clearance assurance system be established. Based upon the outcome of that study, it is further recommended that the technical feasibility of providing such a system within that cost constraint be investigated.

3. It is estimated that by the late 1980's approximately ten airports will require two ground controllers on a regular basis. Preliminary analysis indicates that a Standard Taxiway Routing (STR) system might eliminate the need for adding the second ground controller at all but the two busiest airports, Chigaco O'Hare and Atlanta Hartsfield. Such a system could accrue annual benefits of $63,000 per airport which would pay for a system with initial capital costs of up to $286,000.

The STR equipment is only a general system concept at the present time. Since benefits require fleet equippage with a fully operational DABS data link, priority within the ASTC program has been placed upon resolution of the more imminent bad cab visibility problem. However, as the DABS development program proceeds, the allocation of some resources to conduct preliminary designs, technical feasibility analysis, and revised potential benefits estimation, is recommended.

4. A brief analysis of accidents occurring on the surface of ATC-towered airports from January 1964 to December 1976 indicates that by far the greatest potential for safety improvements exists at the busy air carrier airports. Eighty-seven percent of all accident costs and 76 percent of all fatalities occurred at airports handling more than 100,000 annual air carrier operations. This level of air carrier operations occurred at 25 airports during FY 1977. Safety benefits in good weather conditions (not producible with an ASDE-3) average $66,000 per year per airport which would pay for a system with initial capital costs of up to $304,000.

To identify the cause(s) of the accidents and to permit solutions to be hypothesized and assessed, a detailed study of each accident in this high air carrier activity airport group is required. In view of the significant potential for safety benefits, such a study is recommended.

If TAGS is deployed at three sites, it is possible that enhancements to TAGS aimed at improving safety, might be cost beneficial. Such enhancements include Conflict Alert and DABS/ATARS-based Automatic Intersection Control (AIC). Safety benefits in good weather conditions, which TAGS alone might not accrue, average $93,000 per year per TAGS site and could pay for enhancements with initial capital costs of up to $428,000. The detailed examination of such enhancements should be a part of the recommended ASTC safety study.

5. In addition to enhancements for improved safety, TAGS will provide a platform for other enhancements which may be required by Local Control if metering and spacing and reduced longitudinal separations are utilized. Most of the enhancements require highly accurate aircraft position information in digital form. An accuracy requirement of 16 feet (one standard deviation at 4 samples/second) has been estimated. The potential need for such enhancements and the associated high accuracy requirement has been considered in the selection of a technical alternative for TAGS implementation.

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APPENDIX

IMPROVEMENT FACTOR ESTIMATES

In order to estimate the increased capacity which would result from the deployment of the system alternatives, voice channel communications at several airports have been examined and estimates made of how much reduction in communication time (service time) could be achieved by each alternative. Reduction in service time is assumed to increase the number of aircraft handled. The improved service time divided by the observed (current) service time is defined as the improvement factor. This appendix combines the data contained in the early ASTC requirements analyses of Reference 1.3 with the data obtained at Chicago O'Hare during the ASTC Concept Formulation Study (Reference 1.8), in order to obtain an updated set of improvement factors.

Table A-1 presents the improvement factors contained in Reference 1.3, with TAGS, AIC, and STR contributing to improvements to the Surveillance, Conflict Control, and No Conflict categories, respectively. However, the TAGS system considered in Reference 1.3 included a gate status feature which is no longer included as part of TAGS. This feature was dropped from consideration during the Concept Formulation Study at Chicago O'Hare due to the lack of airline interest, since airline participation was required. Therefore, the TAGS improvement factor was no longer applicable and a new estimate was required.

In generating the new factor, data from Reference 1.8 (Table A-2) is used. In using the data, the detailed message categories of Reference 1.8 are combined into the categories of Reference 1.3 plus "Gate Information," in order to exclude that category from TAGS benefits. The categories are defined in Section 2.1.3. The method of combination (i.e., the detailed categories contained in each major category) is also presented in Table A-2.

TABLE A-1. GOOD VISIBILITY IMPROVEMENT FACTORS

DATA POINTS			IMPROVEMENT FACTORS[1]			
AIRPORT	DATE	TIME	SURVEILLANCE	CONFLICT	NO CONFLICT	OTHER
LAX	1-11-72	1930-2000	.21	.43	.38	1.0
BOS	12-01-71	1630-1700	.34	.44	.40	1.0
LAX	1-11-72	1200-1230	.36	.58	.43	1.0
ORD	1-13-72	1700-1730	.00	.04	.22	1.0
AVERAGE IMPROVEMENTS FACTORS			.23	.37	.36	1.0

(1) $\frac{\text{IMPROVED LOADING ESTIMATE}}{\text{OBSERVED LOADING}}$ FROM TABLE 3-2 OF REFERENCE 1.3

TABLE A-2. MESSAGE LOADING FROM ASTC CONCEPT FORMULATION STUDY

DATA POINTS	NUMBER OF MESSAGES - REFERENCE 1.8						
	SURVEILLANCE						
	POSITION RPT.	OTHER	CONFLICT	NO CONFLICT	OTHER	GATE INFO.	TOTAL
BAD CAB VISIBILITY RUN 8B - 1 HOUR ARRIVALS & DEPARTURES 84 OPERATIONS	195	71	118	145	106	30	665
	266						
GOOD CAB VISIBILITY RUNS 7&9 - 2 HOURS ARRIVALS & DEPARTURES 265 OPERATIONS	83	250	201	352	141	128	1155
	333						
MESSAGE CATEGORIES INCLUDED (SEE REFERENCE 1.8)	(310)	(150) (420) (160)	(120) (140) (111)	(110) (230)	(500) (410) (112)	(311) (470)	

It is assumed in Reference 1.3 that all bad cab visibility capacity limitations are due to increased pilot position reports and that TAGS would fully correct these problems. Therefore, the surveillance service time during bad cab visibility with TAGS was assumed to be the good visibility surveillance time reduced by the good visibility TAGS improvement factor (from Table A-1). In this study, using the Reference 1.8 data, this assumption is reexamined and the improvement factor is updated.

Using the data from Table A-2 and the average saturation capacity estimates from Reference 1.8 (i.e., 85 operations/hour for two ground controllers with ASDE-2 during bad cab visibility, and 175 operations/hour for two ground controllers during good cab visibility), the average messages/aircraft and average service time/aircraft were computed for each major message category. These estimates are given in Table A-3, with average service time/aircraft plotted in Figure 2-10. From these estimates it is seen that increased service time during bad cab visibility conditions is not due solely to the addition of pilot position reports. Therefore, TAGS cannot completely restore all lost capacity and two improvement factors are required, one for bad cab visibility conditions, the other for good cab visibility conditions.

The two TAGS improvement factors are computed as shown in Table A-4. In computing the improved surveillance service time it is assumed that the TAGS identity labels will eliminate the need for all position reports and that the pilot-to-controller-cue using the ATCRBS Ident function will reduce the initial call-in service time of arriving aircraft by two seconds per message. Two seconds is about the time it takes for a pilot to tell the controller where he is and request taxi clearance (e.g., "Global Two Ten, with you off twenty two right" [clearance request assumed]). The two-second reduction in service time was applied only to arrivals (roughly half of the messages) since at busy airports such as Chicago O'Hare, Clearance Delivery takes taxi clearance requests from departing aircraft and cues Ground Control, thus providing the service already.

TABLE A-3. SERVICE TIME DISTRIBUTION (SECONDS/MESSAGE CATEGORY)

Visibility Conditions	MESSAGE CATEGORIES						
	Surveillance						
	Position RPT	Other	Conflict	No Conflict	Other	Gate Info.	Total
Bad Cab Visibility							
Average $\frac{\text{Messages}}{\text{Aircraft}}$	2.32	0.85	1.40	1.73	1.26	0.36	7.92
	$\underbrace{\quad}_{3.17}$						
Average $\frac{\text{Service Time}}{\text{Aircraft}}$ (1)	14.9	5.5	9.0	11.1	8.1	2.3	50.9
	$\underbrace{\quad}_{20.4}$						
Good Cab Visibility							
Average $\frac{\text{Messages}}{\text{Aircraft}}$	0.31	0.94	0.76	1.32	0.53	0.48	4.34
	$\underbrace{\quad}_{1.25}$						
Average $\frac{\text{Service Time}}{\text{Aircraft}}$ (2)	1.8	5.3	4.3	7.5	3.1	2.7	24.7
	$\underbrace{\quad}_{7.1}$						

$$\text{Average } \frac{\text{Service Time}}{\text{Message}} = \text{Saturation Factor} * \#\text{ Controllers} * 3600 \frac{\text{Seconds}}{\text{Hour}} \div \text{Saturation capacity (Aircraft/Hour)} \div \text{Ave } \frac{\text{Messages}}{\text{Aircraft}}$$

(1) $\text{Average } \frac{\text{Service Time}}{\text{Message}} = 0.6 * 3600 \div 85 \div 7.92 = 6.42$ Seconds/Message

(2) $\text{Average } \frac{\text{Service Time}}{\text{Message}} = 0.6 * 3600 \div 175 \div 4.34 = 5.69$ Seconds/Message

TABLE A-4. SUMMARY OF IMPROVEMENT FACTORS USED IN STUDY

Visibility Condition	TAGS Improvement Factor(1) For Surveillance	AIC(4) Improvement Factor for Conflict	STR Improvement Factor For No Conflict
Good Cab Visibility	0.61(2)	0.50	0.36
Bad Cab Visibility	0.23(3)	0.50	0.36

(1) $\frac{\text{Improved Loading Estimate}}{\text{Current Loading}} \overset{\Delta}{=} \text{Improvement Factor}$

$$\text{Tags Improvement Factor} = \frac{\text{Total Surveillance Service Time} - \text{Position Report Service Time} - \text{Initial Call-ins From Arrivals} * \text{2 Seconds Saved By Controller Cue}}{\text{Total Surveillance Service Time}}$$

(2) $\text{Good Visibility Tags Improvement Factor} = \frac{7.1 - 1.8 - (0.94/2)*2}{7.1} = 0.61$

(3) $\text{Bad Visibility TAGS Improvement Factor} = \frac{20.4 - 14.9 - (0.85/2)*2}{20.4} = 0.23$

(4) For 10 units and 80% of potential benefit given in Table A-1.

For the STR and AIC alternatives there was no basis upon which to update the improvement factors for application during bad cab visibility. Therefore, in this study, the good cab visibility factors were used for both visibility conditions. However, for the AIC, an added factor was considered.

From Section 3.3 it is seen that the unit costs for AIC equipment is high. An analysis of the application of AIC equipment to three airports (Chicago O'Hare, Boston Logan, and Los Angeles International) has shown that approximately 25 units are required for full coverage (i.e., to realize all the potential AIC benefits). However, the analysis also demonstrates that 80 percent of the potential AIC benefits can be realized with the installation of only ten units. Installation of each unit beyond ten is of limited benefit, and in view of the high per unit cost it was decided to assume that AIC equipment would be installed in lots of ten (per airport). Costs are estimated accordingly (see Section 3.3) and the AIC improvement factor has been adjusted to reflect the reduced effectiveness (i.e., from 0.37 to 0.50). The improvement factors used in the study are summarized in Table A-4.